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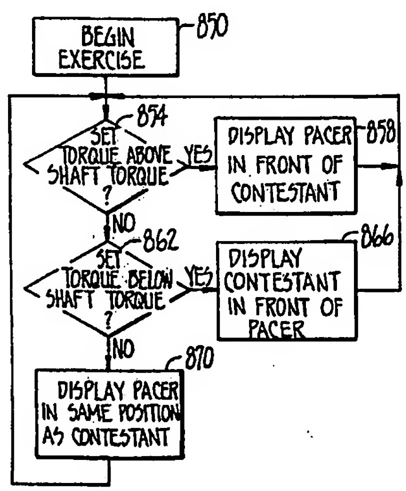

(57) Abstract

A computer control exercise system sequentially and automatically implements isokinetic, isotonic, and isometric exercise types and concentric/concentric, concentric/eccentric and CPM exercise modes so that, once programmed, the physical therapist may attend to other patients while the computer (50) interacts with the patient to effect the desired therapy. The physical therapist may set goals for the patient such as number of repetitions, peak torque, etc., and the computer sets up a life-like contest for the patient using a dynamic pacer (858) and dynamic contestant (866). For example, motion of the patient's body such as lifting or twisting the patient's limb may be converted into a runner which competes against another runner. If the patient meets or exceed the exercise goals, such as number of repetitions or torque applied to the exercise unit, then the runner representing the patient will match or beat the runner representing the goal. Thus, the life-like contest creates internal motivation for the patient to meet his/her exercise goals.

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EXERCISE AND DIAGNOSTIC SYSTEM

BACKGROUND OF THE INVENTION

This invention relates generally to exercise and rehabilitation systems and methods and, more specifically, to an exercise and rehabilitation system which implements a plurality of exercise types and modes and which provides improved patient biofeedback.

One of the major problems facing physical therapists is finding enough time to spend with each patient. Traditionally, the physical therapist would dedicate his or her time to a single patient for a prescribed period of time. The therapist then would act as a coach instructing the patient on each exercise type or mode and then monitoring the patient's performance. Exercise types include isokinetic exercises, wherein motion of a body part is constrained to a constant velocity; an isotonic exercises wherein the body part is exercised with constant torque; and isometric exercises wherein the body part is exercised at zero velocity. Exercise modes include concentric/concentric exercises wherein the body part pushes against the exercise device during both flexion and extension; concentric/eccentric exercises wherein the body part pushes against the exercise device in one direction, and the exercise device pushes against the body part in the other direction; and continuous positive motion (CPM) exercises wherein the exercise device moves the body part at a selected speed for a selected range of motion.

In addition to guiding the patient through the various exercises, the therapist would attempt to provide some sort of motivational coaching in order to overcome a patient's reluctance to meet therapeutic goals because of pain or exhaustion. This coaching often takes the form of screaming at the patient with the concomitant risk of

irritating and angering the patient. That is counter-productive as well as tiring for the therapist. Thus, not only is it desirable to eliminate the time-intensive nature of physical therapy, but it is also desirable to provide alternative forms of patient motivation.

SUMMARY OF THE INVENTION

The present invention is directed to an exercise and diagnostic system wherein a plurality of exercise modes and types may be sequentially and automatically implemented on a single exercise machine and wherein performance biofeedback is provided to the patient in such a way as to internally motivate the patient. In one embodiment of the present invention, a computer control exercise system sequentially and automatically implements isokinetic, isotonic, and isometric exercise types and concentric/concentric, concentric/eccentric and CPM exercise modes so that, once programmed, the physical therapist may attend to other patients while the computer interacts with the patient to effect the desired therapy. The physical therapist may set goals for the patient such as number of repetitions, peak torque, etc., and the computer sets up a life-like contest for the patient using a dynamic pacer and dynamic contestant. For example, motion of the patient's body such as lifting or twisting the patient's limb may be converted into a runner which competes against another runner. If the patient meets or exceeds the exercise goals, such as number of repetitions or torque applied to the exercise unit, then the runner representing the patient will match or beat the runner representing the goal. Thus, the life-like contest creates internal motivation for the patient to meet his/her exercise goals.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an elevational view of a particular embodiment of an exercise system according to the present invention.

Fig. 2 is a partly sectioned elevational view of a particular embodiment of the exercise resistant unit shown in Fig. 1.

Fig. 3 is a partly sectioned elevational view of a particular embodiment of a lever arm assembly according to the present invention.

Fig. 4 is a partially sectioned view taken along lines 4-4 in Fig. 3.

Fig. 5 is an elevational view of an alternate embodiment of a lever arm assembly according to the present invention.

Fig. 6 is a partial block diagram of a particular embodiment of the electrical components of a motion controller according to the present invention.

Figs. 7-15 are flow charts illustrating a particular method of operation of the exercise and diagnostic system according to the present invention.

Fig. 16 is a computer display according to the present invention showing a plurality of exercise types and modes.

Fig. 17 is a flow chart showing a particular execution of multiple exercise types and modes.

Fig. 18 is a computer display showing a particular embodiment of goal types and biofeedback options according to the present invention.

Fig. 19 is a computer display showing a particular embodiment of a bar graph used in the present invention.

Fig. 20 is a computer display showing a particular embodiment of a torque graph used in the present invention.

Fig. 21 is a computer display showing a particular embodiment of a running contest used in the present invention.

Figs. 22-25 are flow charts illustrating particular methods of operation of the running contest shown in Fig. 21.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is preferably incorporated into an overall exercise and diagnostic station which has been designed for maximum utility in patient positioning, optimum flexibility in set up for exercise of various portions of the human body, and minimum involved floor space. For example, as shown in Fig. 1, an exercise and diagnostic station 10 includes an active exercise resistance unit 11, a mounting arrangement 12 and a patient couch 13. The active resistance unit 11 includes a lever arm assembly 14, a patient attachment cuff 15, and a housing 16 which contains a motor 17 (Fig. 2) together with electronic controls. The housing 16 further includes input/output leads 18 which provide measurement signal outputs and control signal inputs between a computer 50 and active resistance unit 11. The details of the electronic components of the exercise and diagnostic system will be discussed below in connection with other drawing figures.

The patient couch arrangement 13 includes two cushion portions 19 and 20 which, together with various positioning elements, provide for positioning of a patient in a sitting or reclining orientation. Which position is selected depends on the patient limb being exercised. In the set-up shown in Fig. 1, the cushion portion 19 serves as a backrest, and the cushion portion 20 serves as a seat. A pair of positioning members 21 control the angular orientation of the cushion portion 19, and a scissors jack type of positioning arrangement 22 controls the forward and backward position of the cushion portion 19. Positioning supports 23 control the angle of the cushion portion 20. To put the patient in a reclining position, the positioning members 23 and 21 are reoriented so that the cushion elements 19 and 20 are horizontal and in line with each other.

The mounting and positioning system 12 includes a vertical pedestal arrangement 24 which includes a rotary support member 25 to which the housing 16 of the active

resistance unit is attached. Preferably a detente arrangement is provided such that the angular orientation of the housing 16 relative to the patient couch can be selectively altered to fixed angeles. A height adjustment jacking arrangement operated by a jack handle 26 is provided within the pedestal 24 to raise and lower the housing 16 for positioning of the axis of rotation of the lever arm assembly 14 relative to the patient.

The pedestal assembly 24 is mounted on a bearing slide arrangement 28 which permits side-to-side movement of the pedestal assembly 24 relative to the patient couch. Another bearing and track arrangement 30A and 30B permits front-to-back movement of the pedestal 24 carried on the bearing and track arrangement 28 and 29. A stabilizing arrangement 31 is provided to rigidly fix the pedestal 24 in a particular selected position relative to the patient couch assembly 13.

Figs. 2-4 illustrate in more detail one embodiment of a lever arm assembly 14. Of course, many types of lever arm assemblies 14 may be provided for exercising different portions of the human body, and different patient attachment devices may be provided in order to provide an appropriate type of interface to the portion of the patient's body to be exercised. Lever arm assembly 14 has a patient attachment cuff 15 which is mounted to the lever arm assembly in a manner such that the patient attachment point is free to move radially during an exercise motion. In the particular embodiment shown in Figs. 2-4, lever arm assembly 14 comprises a hollow square tube 40 having an elongated slot 42 in one corner thereof. An attachment post 41 extends through the slot 42 and, as shown in Fig. 4, is carried on a bearing assembly 50 which traverses the interior of the hollow square tubing 40. A solid end member 56 is attached to one end of the hollow square tubing 40. End member 56 includes an aperture 60 therethrough which permits lever arm assembly 14 to be mounted on shaft 43 as shown in Fig. 2. Shaft 43 extends into the housing 16 and, in a preferred

embodiment, this shaft is part of motor 17 which provides the resistive component of the exercise system. A cable 44 connects the potentiometer arrangement 51 shown in Fig. 3 to the electronic control circuitry which is provided within the housing 16.

The potentiometer arrangement 51 includes a rotary potentiometer 52 which is coupled to a pulley and belt arrangement comprising a first pulley 53 on one end of the lever arm assembly 14, a second pulley 54 mounted on the other end of lever arm assembly 14, and a belt 55. Belt 55 is carried on the two pulleys and is driven by a fixed connection to the carriage assembly 50 which traverses the interior of lever arm assembly 14. Accordingly, as the carriage assembly 50 translates back and forth within the lever arm assembly, the rotary potentiometer 52 is driven to provide a position signal for the electronic circuitry which will be discussed in more detail below. This position signal corresponds to the current lever arm length, i.e., the distance from the center of the shaft to the point of patient attachment which changes during an exercise motion.

Fig. 5 illustrates another embodiment of a lever arm assembly which uses a bearing and track arrangement 72 having a bearing block 71 riding on a pair of tracks 73A and 73B. A potentiometer and first pulley 71 is fastened to the tracks 73 at one end, and a second pulley 75 is provided on the opposite end of the lever arm assembly 70. A continuous belt 76 is attached to the bearing block 71 to drive the potentiometer arrangement as the bearing block 71 translates on the tracks 73. A coupling element similar to attachment post 41 is provided for coupling the bearing block 71 to a patient attachment device. The aperture 74 is used to mount the lever arm assembly to the actuator shaft in the same manner as the corresponding mounting aperture of the lever arm assembly 14.

Fig. 6 is a block diagram of the electronic components of an exercise and diagnostic system according to the present invention. In this embodiment, active exercise

resistance unit 11 comprises a position-based motion controller which controls rotation of lever arm assembly 14 in response to the position of and torque applied to lever arm assembly 14. Of course, the present invention also could be applied to velocity-based and passive systems. Active exercise resistance unit 11 includes potentiometer 52 for measuring limb length, a potentiometer 70 for measuring the angular position of the lever arm, and a strain gauge assembly 75 for measuring the torque applied to lever arm assembly 14. The operation of potentiometer 52 has been discussed above. Potentiometer 70 and strain gauge assembly 75 may be disposed on lever arm assembly 14 in a convenient manner to perform the functions indicated. For example, potentiometer 70 may be mounted on square tubing 40 or shaft 43 for rotation relative to housing 16, whereas strain gauge assembly 75 may be disposed on square tubing 40 or shaft 43 to measure the flexing of the tubing or shaft as a function of applied torque. Active exercise resistance unit 11 further includes a motor 100 for actively controlling the rotation of shaft 43, a brake 104 for maintaining shaft 43 in a fixed position, and an optical encoder 108 for detecting the position of the motor shaft. Optical encoder 108 is calibrated to potentiometer 70 so that optical encoder 108 provides a separate indication of the angular position of the lever arm.

Computer system 50 includes a position/limb length calculator 112 which receives position and limb length signals from potentiometers 52 and 70. Position/limb length calculator 112 provides two signals to a controller 116. One signal indicates the limb length as determined by potentiometer 52, and the other signal indicates the angular position of lever arm assembly 14 as determined by potentiometer 70. A torque calculator 120 receives signals from strain gauge assembly 75 and provides a signal to controller 116 indicating the torque applied to lever arm assembly 14. A power supply 124 receives control signals from controller 116 for controlling the operation of brake

104 and motor 100. A motor position calculator 128 receives signals from optical encoder 108 and provides signals indicating the position of motor 100 to controller 116. The structure and operation of position/limb length calculator 112, torque calculator 120, power supply 124, and motor position calculator 128 are well known and will not be discussed here.

Controller 116 is programmed to regulate the movement of lever arm assembly 14 via motor 100 in response to the position, limb length and torque signals received from position/limb length calculator 112 and torque calculator 120. How this is accomplished is shown in Figs. 7-15.

In operation, computer 50 is powered up, and the operator enters the patient data and desired operating parameters. For example, the operator may specify the isokinetic velocity, the maximum torque, and the maximum range of motion of lever arm assembly 14. Once the range of motion is set, a gravity compensation routine is executed to obtain table values that are used to compensate for the effect of gravity on lever arm assembly 14 throughout the set range of motion. Once the operating parameters are established, the user may enter a number of exercise types and/or modes. For example, the operator may specify a concentric/concentric mode of operation wherein the patient actively pushes on lever arm assembly 14 during both clockwise and counterclockwise motion of lever arm assembly 14. Additional modes include concentric/eccentric and eccentric/concentric modes wherein the patient pushes on lever arm assembly 14 in one direction, and lever arm assembly 14 pushes back in the other direction; a continuous positive motion (CPM) mode wherein lever arm assembly 14 moves the patient's limb in both directions at a prescribed speed; an isometric mode wherein lever arm assembly 14 resists applied force; a move limb mode wherein the patient's limb is moved to a prescribed position within the set range of motion at a selected speed; an idle mode

wherein lever arm assembly 14 is in a passive state; and a lock limb mode wherein lever arm assembly 14 is maintained in a locked position. In concentric/concentric, concentric/eccentric, eccentric/concentric, CPM and move limb modes, torque is limited to the maximum value set by the operator. That is, if the patient pushes on lever arm assembly 14 (or resists the motion of lever arm assembly 14) with a force which produces a torque that exceeds the value set by the operator, then the isokinetic velocity set by the operator is overridden, and the velocity of lever arm assembly 14 is allowed to increase sufficiently to bring the torque within the set maximum.

The operator also may specify a plurality of exercise types. For example, the operator may specify isokinetic exercise at a selected velocity. Isotonic exercise may be achieved by entering concentric/concentric mode with a selected velocity of zero and a nonzero maximum torque. Isometric exercise is achieved by locking lever arm assembly in a fixed position.

The exercise session begins with execution of a MAIN routine shown in Fig. 7. The MAIN routine begins by initializing variables in a step 150. An interwoven interrupt program structure is used in this embodiment, so a 400 hertz interrupt timer is started in a step 154. The arm position and limb length are retrieved in a step 158, and the motor position is retrieved in a step 162. The motor position then is calibrated to the lever position in a step 166. Thereafter, a background routine is performed in a step 170 until the exercise session is ended or aborted.

The background routine executes in a continuing loop unless and until there is a 400 hertz interrupt which causes execution of a 400 hertz routine. After each four executions of the 400 hertz routine, a 100 hertz routine is called. The 100 hertz routine performs the necessary calculations on the input data, whereas the 400 hertz routine ensures that the proper amount of current is supplied to motor 100.

Execution of the background routine begins in a step 174. The background routine is primarily a passive routine which maintains the status quo until the 100 hertz or 400 hertz routines execute. The only time the background routine executes a routine having any effect on the system is when parameters are input to the system, when the range of motion of the lever arm is set, or when gravity compensation for the lever arm is to be performed.

It is then ascertained in a step 178 whether controller 116 has been instructed to obtain parameters from the operator. If so, the parameters (e.g., isokinetic velocity, maximum torque, patient data, etc.) are obtained in a step 182, and execution continues in a step 186 by waiting until the state changes. If parameters are not to be input at this time, then it is ascertained in a step 190 whether controller 116 has been instructed to set the range of motion of lever arm 14 (i.e., set clockwise and counterclockwise stops). If so, then a set stop routine is executed in a step 194. Details of this routine will be discussed in conjunction with Fig. 10B. Once the clockwise and counterclockwise stops are set, processing continues in step 186 until the state changes. If the stops are not to be set at this time, then it is ascertained in a step 198 whether the gravity compensation routine is to be executed. If so, then the gravity compensation routine is executed in a step 202, and processing continues in step 186. Details of the gravity compensation routine will be discussed in conjunction with Fig. 10C.

If gravity compensation is not to be performed at this time, then it is ascertained in steps 206-234 whether one of the valid exercise types or modes or system states has been specified. If so, then processing merely continues in step 186. If none of the valid exercise types or modes or system status has been specified, then system operation ceases in a step 238.

The background routine continues until a 400 hertz interrupt occurs. When the 400 hertz interrupt is received,

the 400 hertz routine begins in a step 280 as shown in Fig. 9. The 400 hertz routine compares the actual motor position with an estimated motor position that was calculated based upon a value, termed VELOUT400, which is a position ramp factor derived from the desired velocity parameter input by the operator. If the calculated motor position does not match the actual motor position, then a current command is given to power supply 124 to increase or decrease the amount of current supplied to motor 100.

As shown in Fig. 9, the actual motor position (derived from the optical encoder) is obtained in a step 284. Thereafter, an error value is determined by subtracting the actual motor position from the calculated motor position in a step 288. The amount of change in the error value from the last time the error value was calculated is determined in a step 292. Then, the change in the error value is scaled and added to the error value in a step 296, and the error value is scaled in a step 300. To predict the motor current required to oppose the torque which caused the error, the present torque is scaled and subtracted from the scaled error value in a step 304. To ensure that the new error value does not represent a current beyond the maximum allowed motor current, the scaled error is limited to the set motor current maximum in a step 308. The scaled and limited error value is sent as a current command to the DAC (not shown) in controller 116 which addresses power supply 124 in a step 312. Finally, the next expected motor position is calculated in a step 316, and the 400 hertz routine is exited in a step 320.

After the 400 hertz routine executes four times, the 100 hertz routine is called. The 100 hertz routine begins in a step 400 shown in Fig. 10A. In general, the 100 hertz routine performs various safety checks and updates the value of VELOUT400 (used to control motor current in the 400 hertz routine) based on the position, limb length, and applied torque signals for each operating state. The 100 hertz routine begins by updating the limb length value in a

step 404. Then it is ascertained in a step 408 whether active exercise resistance unit 11 has been moved to the other side of the patient. If so, then the gravity compensation routine is performed in a step 412 to obtain the proper gravity compensation values for the new position. The gravity compensation routine will be discussed below in conjunction with Fig. 10C. It is then ascertained in a step 416 whether the motor current is at a safe level. This may be determined by modeling the temperature of the motor based on current supplied to the motor. If the motor current is not at a safe level, then the system is halted in a step 420 to ensure the safety of the operator and patient. If the motor current is within safe limits, it is then ascertained in a step 424 whether the motor power should be turned off (e.g., at the end of the exercise session). If so, then motor power is turned off and the brake is turned on in a step 428. Thereafter, the current values for limb length, lever position, motor current and torque are obtained in a step 432. The current and torque values are corrected for any base line errors in a step 436, and the program variables are adjusted in a step 440 to reflect whether resistance unit 11 is placed on the left or right side of the patient. This allows the same programs to be used for system operation independently of whether resistance unit 11 is located on the left or right side of the patient. For example, if position increment values are positive when the patient lifts his or her limb and the unit is located on the right side of the patient, then position increments values will be negative when the patient lifts his or her limb and the unit is located on the left side of the patient since, in the absolute sense, what was once clockwise rotation is now counterclockwise rotation. Setting the sign of the position increment values positive when the unit is located on the left side of the patient eliminates the need to take the location of unit into account for subsequent calculations.

After the variables have been adjusted, it is ascertained in a step 448 (Fig. 10B) whether the motor and lever arm are in their expected position within a prescribed tolerance. If not, the system operation is halted in a step 452. If the expected motor and lever arm positions are within the prescribed tolerance, it is then ascertained in a step 456 whether the motor and lever arm are in the same position relative to each other. This will not be if the attachment of the lever arm to the motor shaft has become loose, if there is a structural failure in the lever arm or if there is a failure of either potentiometer 70 or optical encoder 108. If that is the case, then system operation is halted in a step 460. If all is well up to this point, it is then ascertained in a step 466 whether the lever arm is within the set stops within a prescribed tolerance. If not, then the lever arm was placed in a position outside the permitted range of motion, and the system operation is halted in a step 470. If the lever arm is within the set stops, it is then ascertained in a step 474 whether the motor and lever arm are calibrated within the prescribed tolerance (i.e., they are located in the same position). If not, then system operation is halted in a step 478. If the motor and lever arm are properly calibrated, then it is ascertained in a step 482 whether it has been an overly abrupt change in torque since the last time torque was checked. If so, then system operation is halted in a step 486. If not, then the system proceeds to process the input data to control motor 100 based on the present exercise mode.

The 100 hertz routine typically will not finish executing before the next 400 hertz interrupt. Nevertheless, the 400 hertz routine is given a higher priority. Thus, to avoid conflicts with the 400 hertz routine, the 100 hertz routine does not update the value of VELOUT400 until the 100 hertz routine has completed. In the meantime, the 100 hertz routine works with a prototype of VELOUT400 termed VELOUT.

It is first ascertained in a step 490 whether the system has been set in an idle state. If so, then VELOUT is set to zero in a step 494, and processing continues in a step 498 shown in Fig. 10D. Step 498 limits VELOUT to the maximum machine velocity. Since VELOUT equaled zero in idle mode, this step has no affect on VELOUT. Thereafter, VELOUT is copied into VELOUT400 in a step 502, and the routine is exited in a step 506.

If the system is not set in an idle state, it is then ascertained in a step 510 whether the operator has requested to set the range of motion of the lever arm (i.e., set the stops). If so, then it is ascertained in a step 514 whether the system was in a set stop state the last time it was checked. If not, then the motor position is calibrated to the lever position in a step 518, and motor power is turned on in a step 522. The stops are then set in a step 526. This is accomplished by moving the lever arm to a prescribed position using the cursor control keys on the computer and then storing the clockwise and counterclockwise stop positions. The stops are then limited to the maximum range of motion set for the machine in a step 530. This limitation ensures that the operator cannot set the lever arm range of motion beyond that which is reasonable or safe for the particular machine and patient. Once the stops have been set and properly limited, processing continues in step 498 (Fig. 10D).

If the operator has not requested to set the stop positions, then it is ascertained in a step 534 (Fig. 10C) whether gravity compensation for the lever arm is to be performed. This is desirable after new stops have been set and when the system has been moved from one side of the patient to the other. If gravity compensation is to be performed, then the system automatically moves the lever arm to the counterclockwise stop position in a step 538. Thereafter, the lever arm is moved clockwise in a step 542, and the torque value caused by the effect of gravity on the lever arm for the present position is stored in a table in a

step 546. It is then ascertained in a step 550 whether the clockwise stop has been reached. If not, then the system continues moving the lever arm clockwise and storing corresponding torque values in the table until the clockwise stop is reached. Once the clockwise stop is reached, the lever is moved counterclockwise in a step 554, and a corresponding torque value for the present position is added to the table value previously stored for that position in a step 558. It is then ascertained in a step 562 whether the counterclockwise stop has been reached. If not, then the system continues moving the lever clockwise and adding corresponding torque values in the table until the clockwise stop is reached. Once the counterclockwise stop is reached in step 462, the motor is turned off in a step 566, and processing continues in step 498 (Fig. 10D). When the gravity compensation routine is complete, a sum of two torque values for each lever arm position are stored in the table. The gravity compensation torque value then may be calculated as the average of the two values. Of course, summing and averaging could be done over more than two values if desired. The gravity compensation torque values are added to or subtracted from the sensed torque to ensure that the weight of the lever arm does not affect the patient's ability to use the system for its intended purpose and to ensure that the actual patient effort is monitored and controlled.

If gravity compensation is not to be performed at this time, it is then ascertained in a step 570 whether the system has been set in concentric/concentric mode. If so, then the currently set maximum torque value is stored in a step 574, and the motor is turned on in a step 578. The maximum torque value is used to ensure that the torque applied to the lever arm does not exceed the maximum torque set by the operator. If the patient attempts to exceed this maximum torque limit, then motor 100 accelerates the lever arm to ensure that the set torque maximum is not exceeded.

After the motor is turned on, a concentric motion routine is performed in a step 582. The concentric routine is entered in a step 586 (Fig. 11). The function of the concentric routine is to simulate a flywheel with viscous damping. Accordingly, the absolute value of VELOUT is decreased by a viscous damping factor (determined by the programmer) in a step 590, and then the absolute value of VELOUT is decreased by a desired friction value in a step 594. Thereafter, the absolute value of VELOUT is increased by the amount of torque applied by the patient in a step 598. The torque applied to the lever arm in its present position has been adjusted to compensate for gravity using the gravity compensation tables discussed above. The routine is then exited in a step 602.

Once VELOUT has been altered in the concentric routine, it is necessary to ensure that velocity and torque have not exceeded their prescribed limits, especially when a lever arm is nearing the clockwise or counterclockwise stop position. Thus, a limit velocity routine is first performed in a step 606, a limit torque routine is performed in a step 630, and a soft stop routine is performed in a step 658.

The limit velocity routine is entered in a step 610 (Fig. 12). In this routine, the velocity set by the operator is proportioned in a step 614 to take into account the actual limb length. It is then ascertained in a step 618 whether the absolute value of VELOUT is greater than the proportioned set velocity. If not, the routine is exited in a step 626. If so, then the absolute value of VELOUT is limited to the proportioned set velocity in a step 622, and the routine is exited in step 626.

The limit torque routine is entered in a step 634 (Fig. 14). It is first ascertained in a step 638 whether the set maximum torque limit has been exceeded. If not, then the routine is exited in a step 642. If so, then the adjustment to VELOUT estimated to compensate for the excessive torque is calculated in a step 646. It is then ascertained in a step 650 whether the system is presently in

eccentric mode. Since we are not in eccentric mode, then the calculated adjustment value is added to VELOUT in a step 654, and the routine is exited in step 642.

The soft stop routine is entered in a step 662 (Fig. 13). The soft stop routine ensures smooth acceleration from and deceleration to the clockwise and counterclockwise stops. Thus, it is first ascertained in a step 666 whether the lever arm is within a prescribed distance from the clockwise or counterclockwise stop positions. If not, then the routine is exited in a step 670. If so, then the system obtains a deceleration factor from a table, and a deceleration speed is calculated from the deceleration factor. The deceleration factor table is addressed by the lever arm position. It is then ascertained in a step 678 whether the value of VELOUT is greater than the deceleration speed. If so, then VELOUT is set to the deceleration speed in a step 682, and the routine is exited in step 670.

After the soft stop routine is performed, processing continues in step 498 (Fig. 10D).

If the system is not in concentric/concentric mode, it is then ascertained in a step 686 whether the system is in concentric/eccentric or eccentric/concentric mode. In these modes, the patient exerts force on the lever arm in one direction of motion, and the lever arm exerts force on the patient in the other direction of motion. As in concentric/concentric mode, the maximum torque is set in a step 690, and the motor is turned on in a step 694. A CONECC routine is then performed in a step 698.

The CONECC routine begins in a step 702 (Fig. 15). The routine initially determines whether the lever arm is within a prescribed distance e.g., 1°, of either the clockwise or counterclockwise stop in a step 706. If so, then the system is to change from concentric mode to eccentric mode or vice versa, and it is ascertained in a step 710 which mode is to be performed next. If eccentric mode is to be performed next, then a peak torque value is

set to one half the peak torque value obtained from the previous concentric phase of the routine. This peak torque value is used to set the minimum torque applied to the patient's limb by the lever arm in eccentric mode. The limb is thus exercised based upon the patient's actual performance rather than some theoretical torque set by the operator. Thereafter, it is determined in a step 718 whether the system is now in concentric or eccentric mode. If the system is in concentric mode, then the current torque applied to the lever arm by the patient is stored in a torque array in a step 722, and it is ascertained in a step 726 whether this is the largest torque encountered in this set. If so, then the peak torque (used in eccentric mode as noted above) is set to the present torque in a step 730. If not, then the concentric routine is performed in a step 734. This concentric routine is the same concentric routine shown in Fig. 11. Once the concentric routine is finished, the routine is exited in a step 738.

If it is ascertained in step 718 that the system is in eccentric mode, then the present lever arm position is used in a step 742 to address the torque array that was filled the last time the system was in concentric mode. It is then ascertained in a step 746 whether the peak torque (equal to one half the peak torque encountered the last time the system was in concentric mode) is greater than the addressed torque array value. If so, then the torque to be applied by the lever arm to the patient is set to the peak torque value in a step 750; otherwise the lever arm torque is set to the value stored in the torque array in a step 754. The selected torque value is then scaled in a step 758 to take into account the fact that limbs may be stronger when exercising eccentrically. In this embodiment, the table value is multiplied by 1.5. Finally, the upper torque limit is set to the scaled torque value in a step 762.

The net effect of these torque calculations is that the torque applied to the lever arm by the patient during the last concentric phase is used as a basis for the

torque applied to the patient's limb during the eccentric phase, with a minimum torque equal to one half the peak torque encountered during the concentric phase. If the patient is able to resist the lever arm with greater torque than the scaled torque value, then the torque will be limited by the set upper torque limit.

After the CONECC routine is performed, the limit velocity routine is performed in a step 766, the limit torque routine is performed in a step 770, and the soft stop routine is performed in a step 774. These routines are essentially the same as those shown in Figs. 12, 14, and 13, respectively. The only difference is that, in the limit torque routine (Fig. 14), the execution path changes slightly at step 650 when the system is in eccentric mode. In this case it is then ascertained in a step 775 whether the calculated velocity change will operate to decrease VELOUT. If not, then processing continues in step 654. If so, then it is ascertained in a step 776 whether the calculated velocity change is greater than the current value of VELOUT. If not, then processing continues in step 654. If so, then the velocity change is set to -VELOUT, and processing continues in step 654. The net effect of these calculations is to allow the patient to slow down the lever arm or stop it, but to prevent the patient from reversing direction of rotation.

If the system is not in one of the concentric/eccentric or eccentric/concentric modes, then it is ascertained in a step 778 whether the system is in CPM mode. If so, then the maximum torque is set in a step 782, and the motor is turned on in a step 786. VELOUT is then set to the maximum velocity set by the operator in a step 790 since it is presumed that the patient will not be pushing on the lever arm or resisting the lever arm motion. Nevertheless, the limit velocity routine is performed in a step 794, the limit torque routine is performed in a step 798, and the soft stop routine is performed in a step 802 to ensure that the velocity of and torque applied to the lever

arm are in fact the within the proper limits. After the soft stop routine is performed in step 802, processing continues in step 498 (Fig. 10D).

If the system is not in CPM mode, it is then ascertained in a step 806 (Fig. 10D) whether the system is to effect an isometric exercise. If so, then the motor is turned off in a step 810, and the motor brake is turned on in a step 814. Of course, VELOUT is set to 0 in this case. Processing then continues in step 498.

If the system is not effecting an isometric exercise, then it is determined in a step 818 whether the system is in a move limb state. In this state, the lever arm moves to a position indicated by the operator. Thus, the motor is turned on in a step 822, and the maximum torque is set in a step 824. Thereafter, the lever arm (and the patient's limb) is moved to the desired position in a step 828. The velocity used in this mode is set by the programmer or may be entered manually. Thereafter, the limit torque routine is performed in a step 832, and the soft stop routine is performed in a step 836. Once the desired position is reached, the state is set to idle in a step 840, and processing continues in step 498.

If the system is not in a move limb state, it is then ascertained in a step 844 whether the system is in a parameter entry state. If so, then the motor is turned off in a step 848, and parameters entered by the operator are accepted by the system in a step 852. Processing then continues in step 498.

If the system is not in a parameter entry state, it is then ascertained in a step 856 whether the system is in a lock limb state. If so, the motor is turned off in a step 860 and the brake is turned on in a step 864. Processing then continues in step 498.

If the system is not in a lock limb state, then a system error exists, and the system is halted in a step 868.

Exercise Session and Patient Biofeedback

The method of implementing the exercise and diagnostic system according to the present invention may be extended to produce a more complete system with advantages previously unobtainable by known systems. For example, the techniques described above may be used to sequentially implement a plurality of exercise types and modes during a single exercise session. Fig. 16 illustrates an exercise session wherein nine exercise bouts are programmed using the parameter entry feature. The exercise mode, desired velocity, number of repetitions or duration, rest period, number of sets and torque limits are set for each bout. The exercise session then begins in a step 800 (Fig. 17). It is ascertained in a step 804 whether the last exercise bout has been completed. If so, then the session is ended in a step 808. If not, the system state is set to the next exercise mode/type. The programmed exercise then begins in a step 816. It is then ascertained in a step 820 whether the number of repetitions programmed for that exercise mode/type has been completed. If so, then it is ascertained in a step 824 whether the number of sets programmed for that exercise mode/type has been completed. If so, then processing continues in step 804. If the number of repetitions has not been completed (or has not been programmed), it is then ascertained in a step 828 whether the duration programmed for that exercise mode/type has elapsed. If not (or if duration has not been programmed), then the programmed exercise continues in step 816. If the programmed time duration has elapsed, then processing continues in step 824.

In addition to effecting the plurality of exercise types and modes in a single exercise session, it is possible to provide the patient with different goal types and self-motivating biofeedback. Fig. 18 illustrates a computer screen wherein different goal types and biofeedback options have been specified. Goal types include peak torque, work per repetition, total work and power. Biofeedback options include a bar graph (Fig. 19), a torque curve (Fig. 20) or a

contest with a runner (Fig. 21). As shown in Fig. 19, the bar graph may display the set goal (e.g., 100 ft. lbs. torque), instructions to the patient (e.g., an up arrow for lifting a limb), maximum torque so far achieved (e.g., 57 ft. lbs. indicated by a movable line), amount of effort presently being exerted (e.g., by the vertical bar), number of repetitions completed (e.g. 4) and time elapsed (e.g., 20 seconds).

As shown in Fig. 20, the torque graph may display torque achieved for each position during extension and flexion.

Fig. 21 illustrates a particularly motivating form of biofeedback wherein the patient engages in a life-like contest with a dynamic pacer. In this embodiment, the patient engages in a running contest wherein the patient, depicted as a runner contestant, races the dynamic pacer, also depicted as a runner, across the computer display. Although runners have been shown, it should be understood that the contestant and pacer may take many forms, e.g., two race cars, etc. Operation of the embodiment shown in Fig. 21 may be understood by referring to Figs. 22-25.

Fig. 22 shows operation of the contest when the goal is peak torque. Exercise begins in a step 850. It is then ascertained in a step 854 whether the set torque is above the torque applied to the motor shaft by the patient. If so, then the pacer runs ahead of the contestant (patient) in a step 858, and the race continues in step 854. If the set torque is not above the torque applied to the motor shaft by the patient, it is then ascertained in a step 862 whether the set torque is below the shaft torque. If so, then the patient is exceeding his/her goal, the contestant runs ahead of the pacer in a step 866, and the race continues. If the set torque is not below the shaft torque, then the patient is exactly meeting the set torque and the pacer is displayed running in the same position as the contestant in a step 870. This operation continues until

the exercise is complete (number of repetitions or duration).

Fig. 23 shows operation of the contest when the goal is the number of repetitions, independent of time. Exercise begins in a step 880. It is then ascertained in a step 884 whether the number of repetitions is below the number of set repetitions. If so, then the pacer is displayed running in front of the contestant in a step 888, and the race continues. If the number of repetitions is not below the number of set repetitions, then the goal has been reached, and the pacer is displayed in the same position as the contestant in a step 892. Of course, it may be desirable to place the contestant slightly ahead of the pacer when the goal has been met to provide added patient satisfaction. Once the goal has been reached, the exercise bout ends in a step 896.

Fig. 24 shows operation of the contest when the goal is number of repetitions in a prescribed time interval. The exercise session begins in a step 900. It is then ascertained in a step 904 whether the set time has expired. If so, the final positions of the runners are displayed in a step 908. If the time has not yet expired, the pacer is advanced in a step 912. The amount by which the pacer advances may be determined by dividing the width of the computer display screen by the time interval to determine how quickly the pacer must advance. In addition to advancing the pacer, the contestant is advanced by the number of repetitions completed. In this case, the width of the computer display screen may be divided by the number of programmed repetitions, and the contestant advances according to the number of repetitions completed. Processing then continues in step 904.

Fig. 25 shows operation of the contest when the goal is total angular distance moved by the motor shaft in a prescribed interval of time. The exercise session begins in a step 930. It is then ascertained in a step 934 whether the set time has expired. If so, then the final positions

of the runners are displayed in a step 938. If not, then the pacer is advanced in a step 942. The amount by which the pacer advances may be determined by dividing the width of the computer display screen by the time interval and then advancing the pacer accordingly. Thereafter, the contestant is advanced according to the distance completed by the patient in a step 946. The amount by which the contestant is advanced may be determined by dividing the width of the computer display by the total distance to be covered.

While the above is a complete description of a preferred embodiment of the present invention, various modifications may be employed. For example, the teachings of the present invention may be applied to many exercise devices as shown in U.S. Patent application no. 07/472,399 entitled "Position Based Motion Controller" and incorporated herein by reference. Consequently, the scope of the invention should not be limited except as described in the claims.

WHAT IS CLAIMED IS:

1. In a muscle exercise and diagnostic system having a shaft for defining a fixed axis of rotation and body interface means for coupling motion of a live body to the shaft so that the shaft rotates together with motion of the body, a motion controller comprising:

torque sensing means, coupled to the shaft, for sensing an amount of torque applied to the shaft by the body and for providing a torque signal in response thereto;

constant velocity means, coupled to the torque sensing means and to the shaft, for rotating the shaft at a constant velocity in response to the torque signal;

first exercise mode means, coupled to the shaft, for controlling rotation of the shaft for effecting a first exercise mode;

second exercise mode means, coupled to the shaft, for controlling rotation of the shaft for effecting a second exercise mode;

exercise mode selecting means for selecting a sequence of exercise modes including a plurality of the first or second exercise modes; and

exercise mode effecting means, coupled to the exercise mode selecting means and to the constant velocity means, for controlling the rotation of the shaft for automatically effecting the sequence of exercise modes.

2. In a muscle exercise and diagnostic system having a shaft for defining a fixed axis of rotation and body interface means for coupling motion of a live body to the shaft so that the shaft rotates together with motion of the body, a motion controller comprising:

first exercise type means, coupled to the shaft, for controlling rotation of the shaft for effecting a first exercise type;

second exercise type means, coupled to the shaft, for controlling rotation of the shaft for effecting a second exercise type;

exercise type selecting means for selecting a sequence of exercise types including a plurality of the first or second exercise types; and

exercise type effecting means, coupled to the first and second exercise type means and to the exercise type selecting means, for controlling rotation of the shaft for automatically effecting the sequence of exercise types.

3. The motion controller according to claim 2 wherein the first exercise type comprises an isokinetic exercise, and wherein the second exercise type comprises an isotonic exercise.

4. The motion controller according to claim 2 wherein the first exercise type comprises an isokinetic exercise, and wherein the second exercise type comprises an isometric exercise.

5. The motion controller according to claim 2 wherein the first exercise type comprises an isotonic exercise, and wherein the second exercise type comprises an isometric exercise.

6. The motion controller according to claim 2 further comprising:

torque sensing means, coupled to the shaft, for sensing an amount of torque applied to the shaft by the body and for providing a torque signal in response thereto;

constant velocity means, coupled to the torque sensing means and to the shaft, for rotating the shaft at a constant velocity in response to the torque signal;

first exercise mode means, coupled to the shaft, for controlling rotation of the shaft for effecting a first exercise mode;

second exercise mode means, coupled to the shaft, for controlling rotation of the shaft for effecting a second exercise mode;

exercise mode selecting means for selecting a sequence of exercise modes including a plurality of the first or second exercise modes; and

exercise mode effecting means, coupled to the exercise mode selecting means and to the constant velocity means, for controlling the rotation of the shaft for automatically effecting the sequence of exercise modes.

7. The motion controller according to claim 2 wherein the first exercise mode comprises a concentric/concentric exercise, and wherein the second exercise mode comprises a concentric/eccentric exercise.

8. The motion controller according to claim 2 wherein the first exercise mode comprises a concentric/concentric exercise, and wherein the second exercise mode comprises a continuous passive motion exercise.

9. The motion controller according to claim 2 wherein the first exercise mode comprises a concentric/eccentric exercise, and wherein the second exercise mode comprises a continuous passive motion exercise.

10. The motion controller according to claim 6 further comprising:

third exercise type means, coupled to the shaft, for controlling rotation of the shaft for effecting a third exercise type;

third exercise mode means, coupled to the shaft, for controlling rotation of the shaft for effecting a third exercise mode;

wherein the sequence of exercise types includes the first, second or third exercise types; and

wherein the sequence of exercise modes includes the first, second or third exercise modes.

11. The motion controller according to claim 10 wherein:

the first exercise type comprises an isokinetic exercise;

the second exercise type comprises an isotonic exercise;

the third exercise type comprises an isometric exercise;

the first exercise mode comprises a concentric/concentric exercise;

the second exercise mode comprises a concentric/eccentric exercise; and

the third exercise mode comprises a continuous positive motion exercise.

12. In a muscle exercise and diagnostic system having a shaft for defining a fixed axis of rotation and body interface means for coupling motion of a patient to the shaft so that the shaft rotates together with motion of the patient, a patient biofeedback apparatus comprising:

parameter setting means for setting a value of a shaft parameter to represent an exercise goal;

parameter sensing means, coupled to the shaft, for sensing the value of the shaft parameter and for providing a parameter indicating signal in response thereto;

dynamic pacer display means for displaying a dynamic pacer on a computer display;

contestant display means for displaying a contestant on the computer display;

parameter comparing means, coupled to the parameter setting means and to the parameter sensing means, for comparing the set parameter to the sensed parameter and

for providing a parameter relationship signal in response thereto;

display control means, coupled to the parameter comparing means, to the pacer display means, and to the contestant display means, for controlling displayed positions of the contestant and the pacer in response to the parameter relationship signal; and

wherein a displayed position of the contestant matches a displayed position of the dynamic pacer when the value of the shaft parameter substantially matches the set parameter.

13. The apparatus according to claim 12 wherein the displayed position of the contestant is behind the displayed position of the pacer when the value of the shaft parameter is below the set parameter.

14. The apparatus according to claim 13 wherein the displayed position of the contestant is ahead of the displayed position of the pacer when the value of the shaft parameter is above the set value.

15. The apparatus according to claim 12 wherein the shaft parameter is torque applied to the shaft by the patient.

16. The apparatus according to claim 12 wherein the parameter is a number of times the shaft rotates a prescribed distance.

17. The apparatus according to claim 12 wherein the parameter is a number of times the shaft rotates a prescribed distance for a prescribed time interval.

18. The apparatus according to claim 12 wherein the parameter is a distance the shaft rotates in a prescribed time interval.

19. The apparatus according to claim 12 wherein the display control means further comprises:

pacer advancing means for advancing the displayed position of the pacer when the set parameter is above the shaft parameter; and

contestant advancing means for advancing the displayed position of the contestant when the set parameter is below the shaft parameter.

20. The apparatus according to claim 19 wherein the contestant comprises a runner, and wherein the pacer comprises a runner.

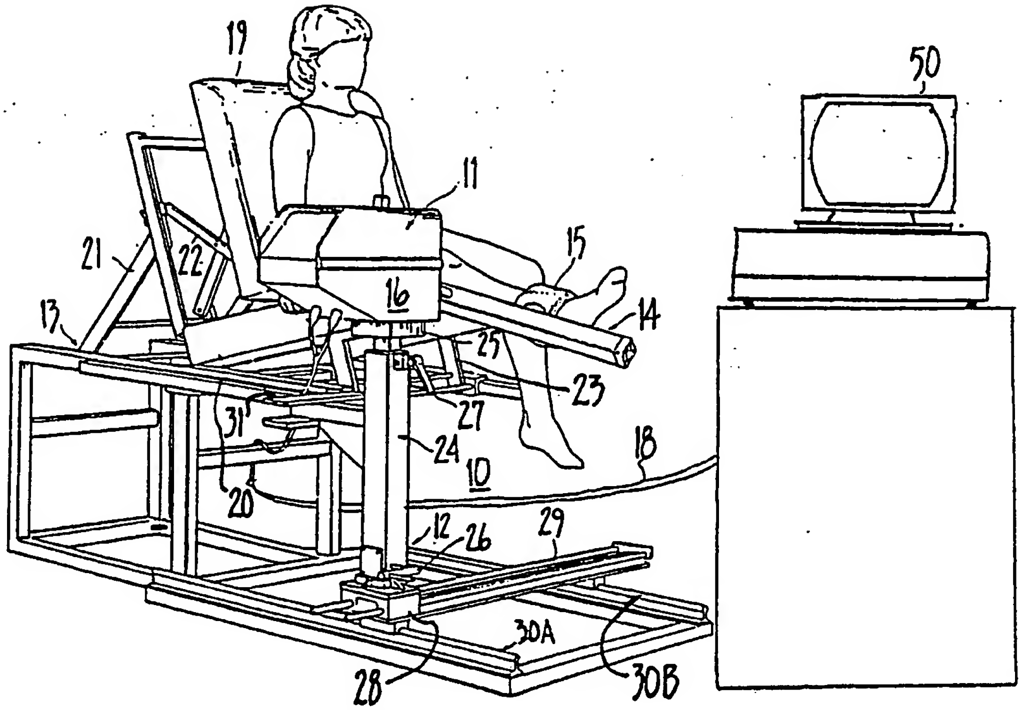

19
50
11
21
22
15
16
13
14
25
23
31
27
24
18
10
20
12
26
29
30A
28
30B

FIG._1.

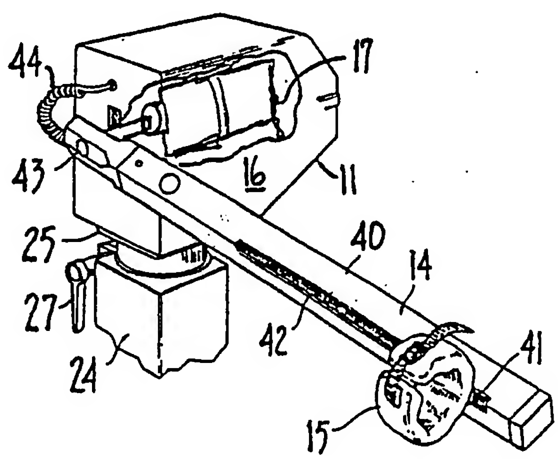

44
17
43
16
11
25
40
14
27
42
41
24
15

FIG._2.

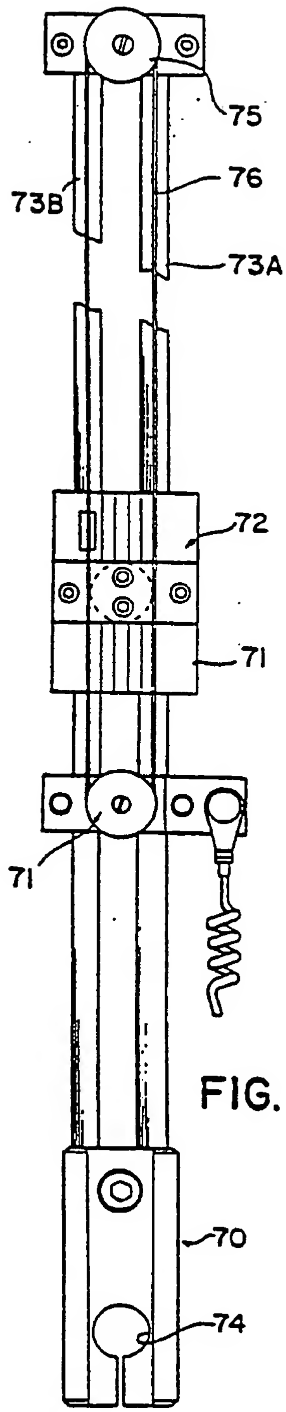


FIG. 5

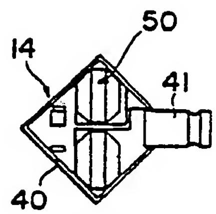


FIG. 4

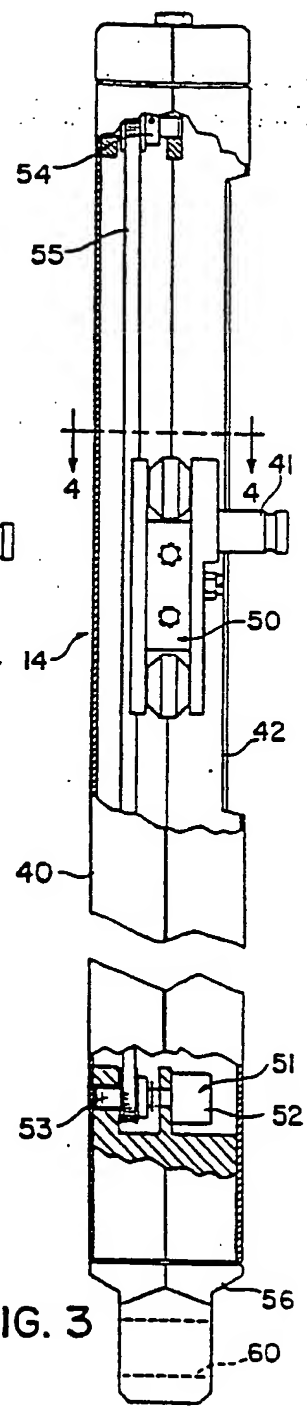
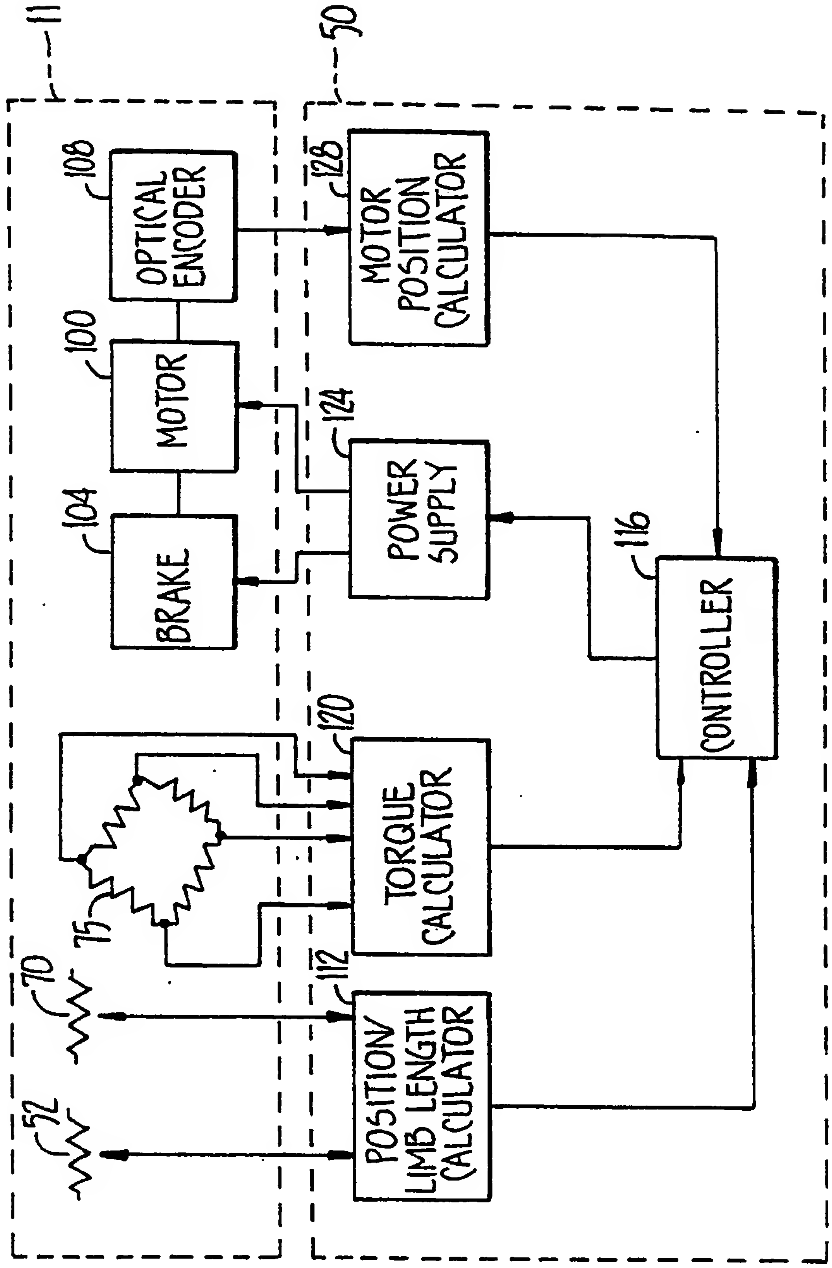
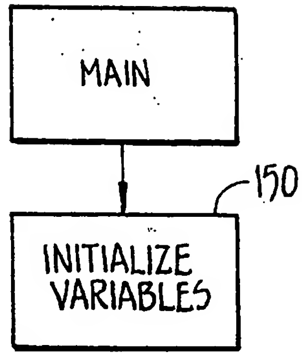


FIG. 3



11
50
108
OPTICAL ENCODER
100
MOTOR
104
BRAKE
128
MOTOR POSITION CALCULATOR
124
POWER SUPPLY
116
CONTROLLER
120
TORQUE CALCULATOR
75
70
52
112
POSITION/ LIMB LENGTH CALCULATOR

FIG._6.


MAIN
150
INITIALIZE VARIABLES

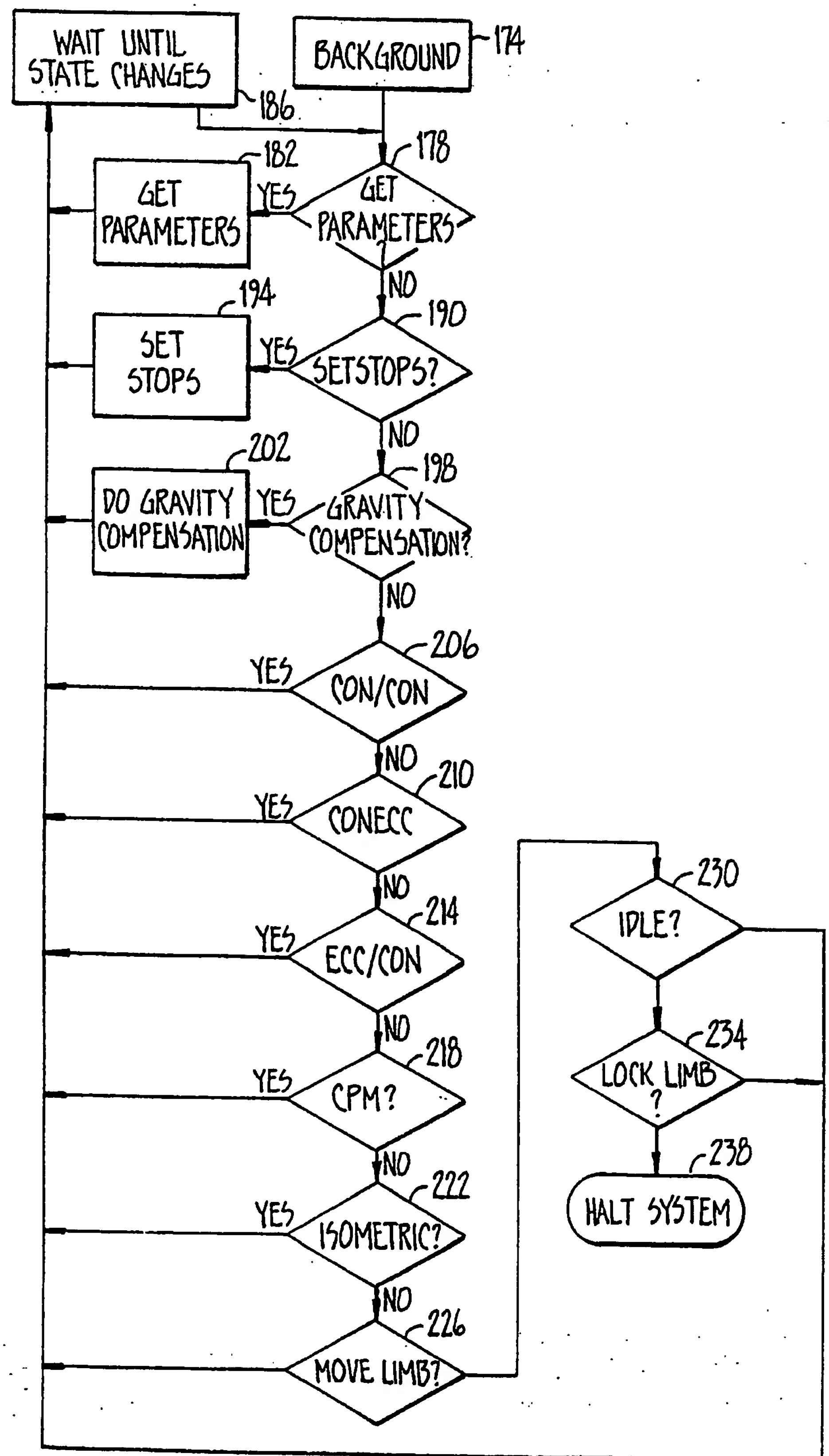

WAIT UNTIL STATE CHANGES
186
BACKGROUND
174
178
182
GET PARAMETERS
YES
GET PARAMETERS?
NO
194
190
SET STOPS
YES
SETSTOPS?
NO
202
198
DO GRAVITY COMPENSATION
YES
GRAVITY COMPENSATION?
NO
206
YES
CON/CON
NO
210
YES
CONECC
NO
214
YES
ECC/CON
NO
218
YES
CPM?
NO
222
YES
ISOMETRIC?
NO
226
MOVE LIMB?
230
IDLE?
234
LOCK LIMB?
238
HALT SYSTEM

FIG._8.

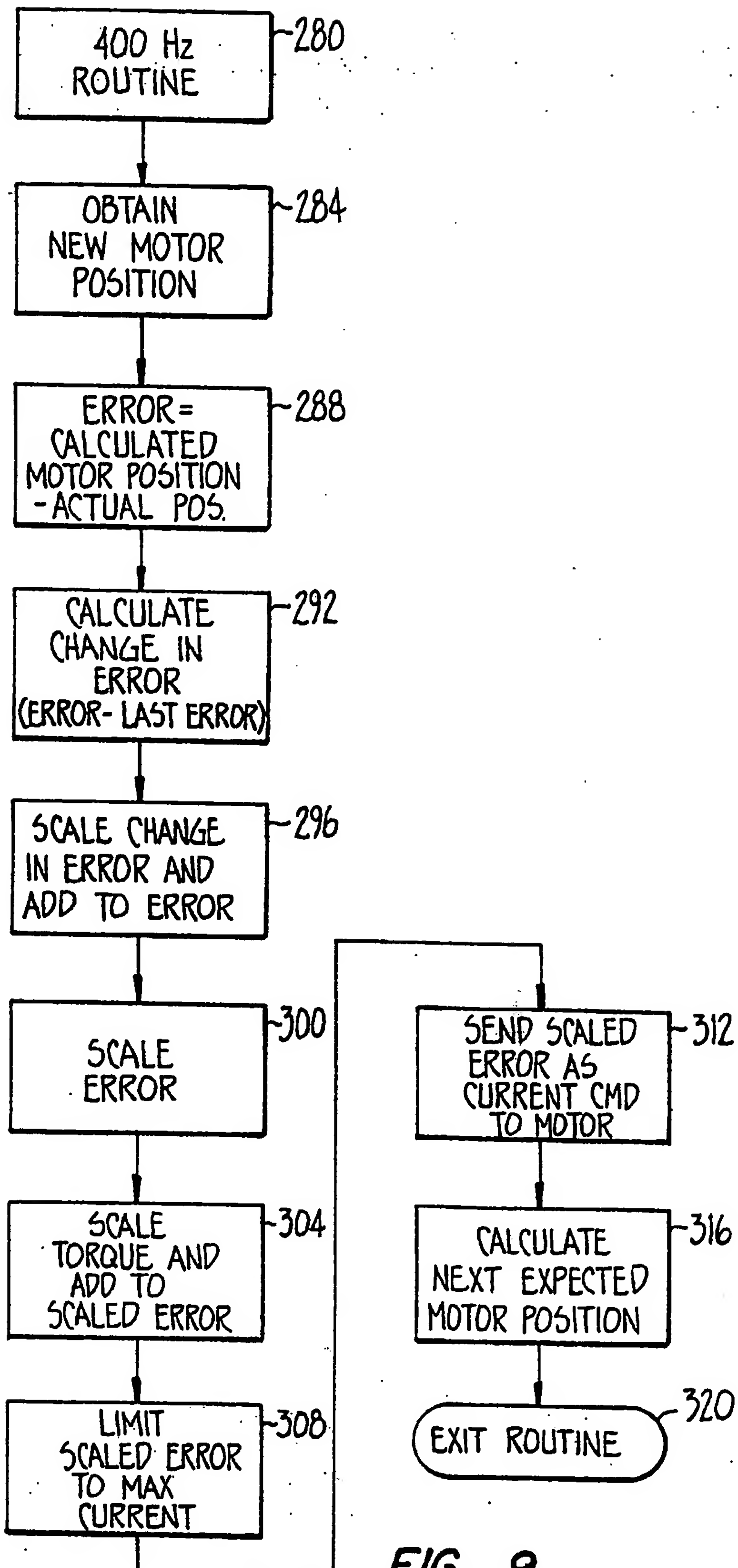

400 Hz ROUTINE
280
OBTAIN NEW MOTOR POSITION
284
ERROR= CALCULATED MOTOR POSITION -ACTUAL POS.
288
CALCULATE CHANGE IN ERROR (ERROR- LAST ERROR)
292
SCALE CHANGE IN ERROR AND ADD TO ERROR
296
SCALE ERROR
300
SCALE TORQUE AND ADD TO SCALED ERROR
304
LIMIT SCALED ERROR TO MAX CURRENT
308
SEND SCALED ERROR AS CURRENT CMD TO MOTOR
312
CALCULATE NEXT EXPECTED MOTOR POSITION
316
EXIT ROUTINE
320

FIG._9.

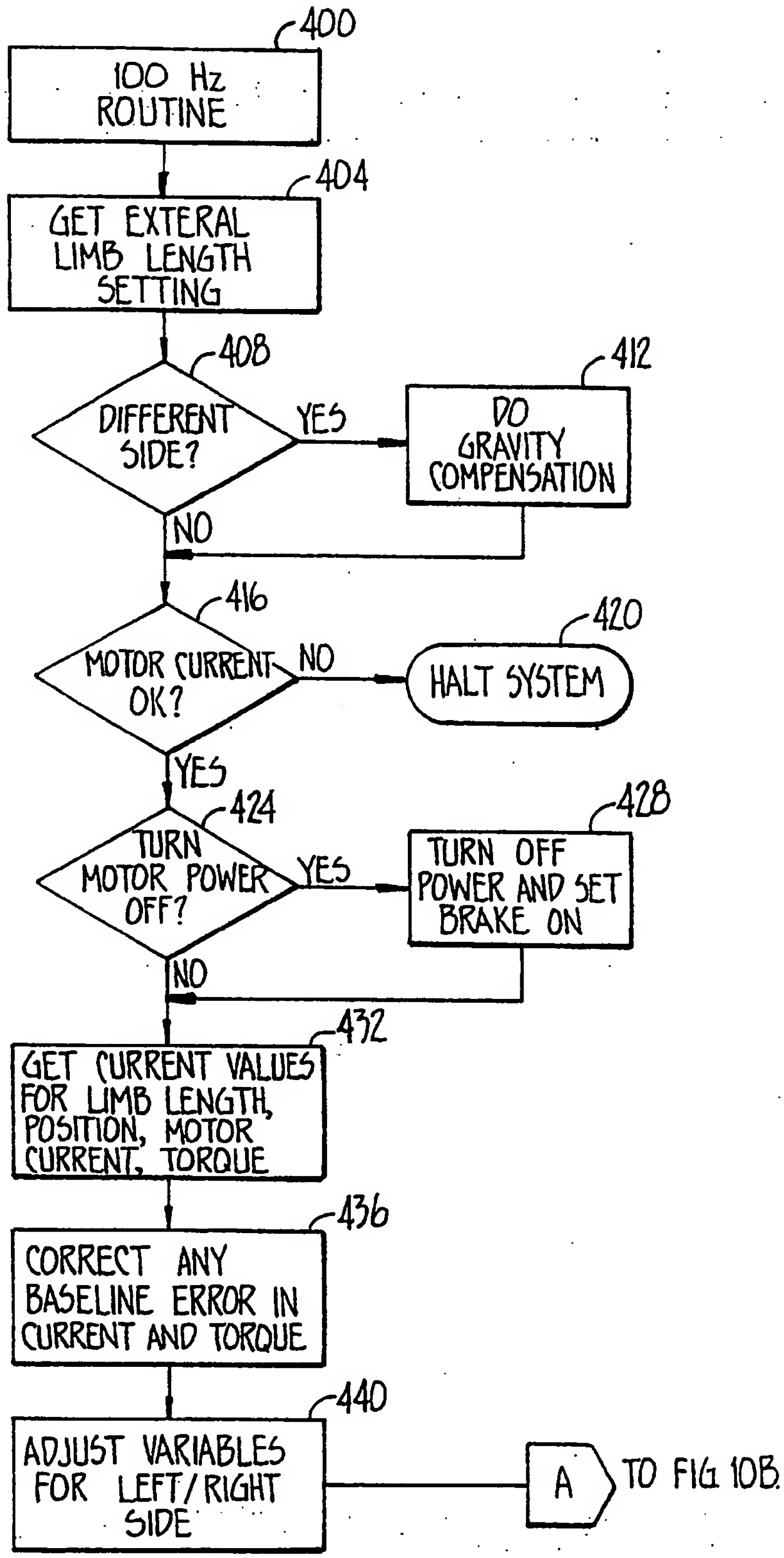

400
100 Hz ROUTINE
404
GET EXTERAL LIMB LENGTH SETTING
408
DIFFERENT SIDE?
YES
412
DO GRAVITY COMPENSATION
NO
416
MOTOR CURRENT OK?
NO
420
HALT SYSTEM
YES
424
TURN MOTOR POWER OFF?
YES
428
TURN OFF POWER AND SET BRAKE ON
NO
432
GET CURRENT VALUES FOR LIMB LENGTH, POSITION, MOTOR CURRENT, TORQUE
436
CORRECT ANY BASELINE ERROR IN CURRENT AND TORQUE
440
ADJUST VARIABLES FOR LEFT/RIGHT SIDE
A
TO FIG 10B

FIG._10A.

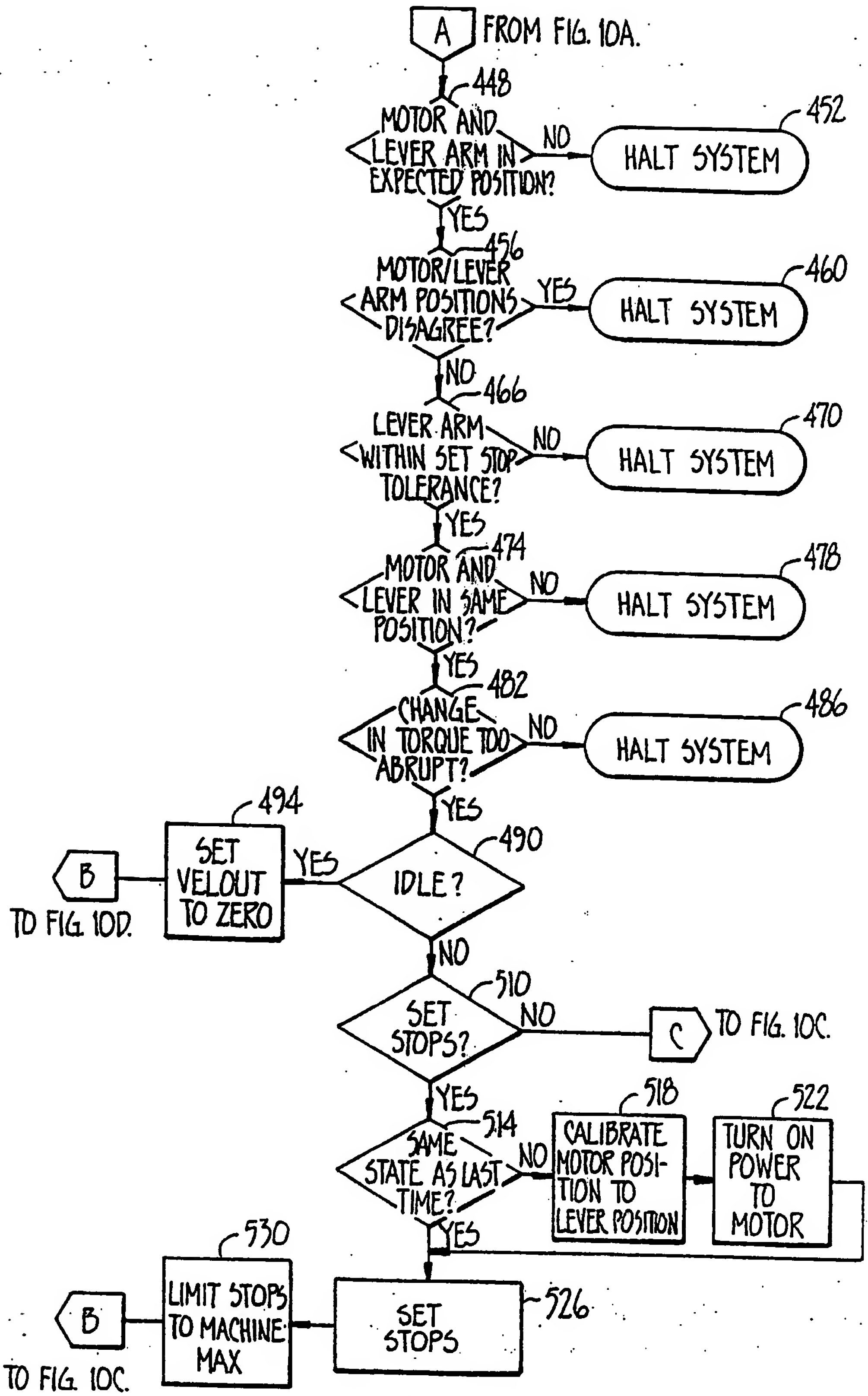

A
FROM FIG. 10A.
448
MOTOR AND LEVER ARM IN EXPECTED POSITION?
NO
HALT SYSTEM
452
YES
456
MOTOR/LEVER ARM POSITIONS DISAGREE?
YES
HALT SYSTEM
460
NO
466
LEVER ARM WITHIN SET STOP TOLERANCE?
NO
HALT SYSTEM
470
YES
474
MOTOR AND LEVER IN SAME POSITION?
NO
HALT SYSTEM
478
YES
482
CHANGE IN TORQUE TOO ABRUPT?
NO
HALT SYSTEM
486
YES
490
IDLE?
YES
494
SET VELOUT TO ZERO
B
TO FIG. 10D.
NO
510
SET STOPS?
NO
C
TO FIG. 10C.
YES
514
SAME STATE AS LAST TIME?
NO
518
CALIBRATE MOTOR POSITION TO LEVER POSITION
522
TURN ON POWER TO MOTOR
YES
526
SET STOPS
530
LIMIT STOPS TO MACHINE MAX
B
TO FIG. 10C.

FIG._10B.

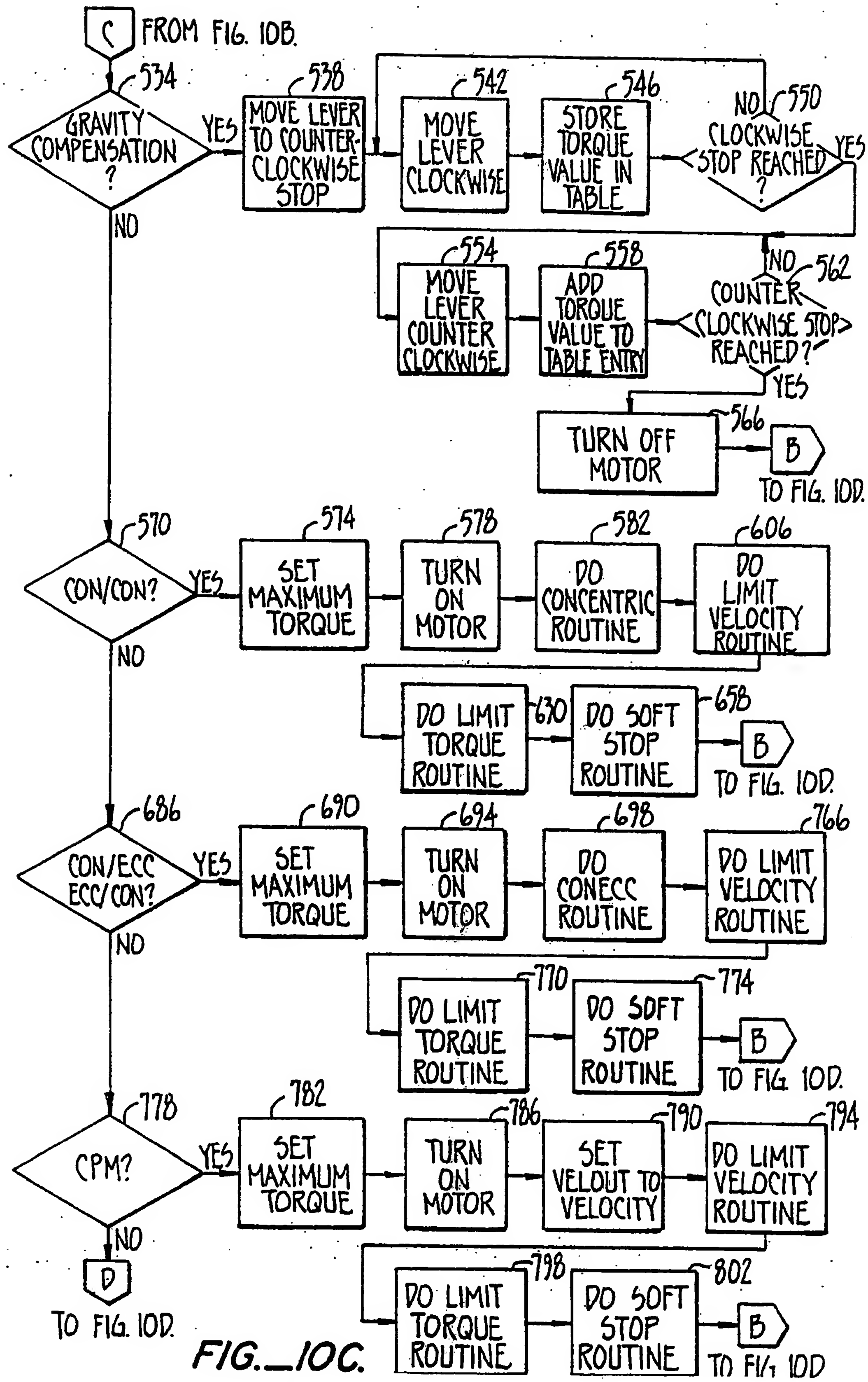

C
FROM FIG. 10B.
534
GRAVITY COMPENSATION ?
YES
NO
538
MOVE LEVER TO COUNTER-CLOCKWISE STOP
542
MOVE LEVER CLOCKWISE
546
STORE TORQUE VALUE IN TABLE
550
NO
CLOCKWISE STOP REACHED ?
YES
554
MOVE LEVER COUNTER CLOCKWISE
558
ADD TORQUE VALUE TO TABLE ENTRY
562
NO
COUNTER CLOCKWISE STOP REACHED?
YES
566
TURN OFF MOTOR
B
TO FIG. 10D.
570
CON/CON?
YES
NO
574
SET MAXIMUM TORQUE
578
TURN ON MOTOR
582
DO CONCENTRIC ROUTINE
606
DO LIMIT VELOCITY ROUTINE
630
DO LIMIT TORQUE ROUTINE
658
DO SOFT STOP ROUTINE
B
TO FIG. 10D.
686
CON/ECC ECC/CON?
YES
NO
690
SET MAXIMUM TORQUE
694
TURN ON MOTOR
698
DO CONECC ROUTINE
766
DO LIMIT VELOCITY ROUTINE
770
DO LIMIT TORQUE ROUTINE
774
DO SOFT STOP ROUTINE
B
TO FIG. 10D.
778
CPM?
YES
NO
D
TO FIG. 10D.
782
SET MAXIMUM TORQUE
786
TURN ON MOTOR
790
SET VELOUT TO VELOCITY
794
DO LIMIT VELOCITY ROUTINE
798
DO LIMIT TORQUE ROUTINE
802
DO SOFT STOP ROUTINE
B
TO FIG. 10D

FIG._10C.

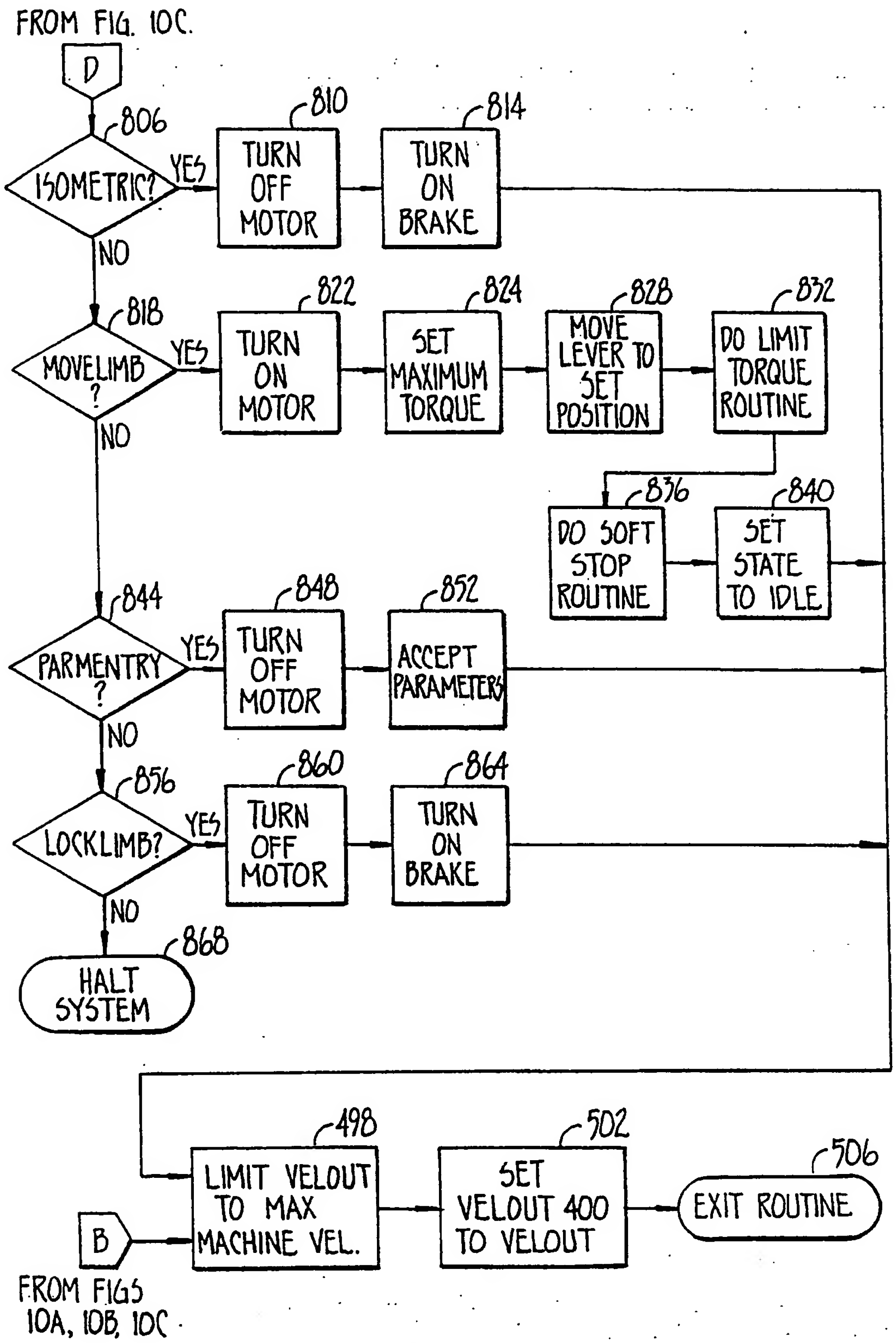

FROM FIG. 10C.
D
806
ISOMETRIC?
YES
NO
810
TURN OFF MOTOR
814
TURN ON BRAKE
818
MOVELIMB ?
YES
NO
822
TURN ON MOTOR
824
SET MAXIMUM TORQUE
828
MOVE LEVER TO SET POSITION
832
DO LIMIT TORQUE ROUTINE
836
DO SOFT STOP ROUTINE
840
SET STATE TO IDLE
844
PARMENTRY ?
YES
NO
848
TURN OFF MOTOR
852
ACCEPT PARAMETERS
856
LOCKLIMB?
YES
NO
860
TURN OFF MOTOR
864
TURN ON BRAKE
868
HALT SYSTEM
498
LIMIT VELOUT TO MAX MACHINE VEL.
502
SET VELOUT 400 TO VELOUT
506
EXIT ROUTINE
B
FROM FIGS 10A, 10B, 10C

FIG._10D.

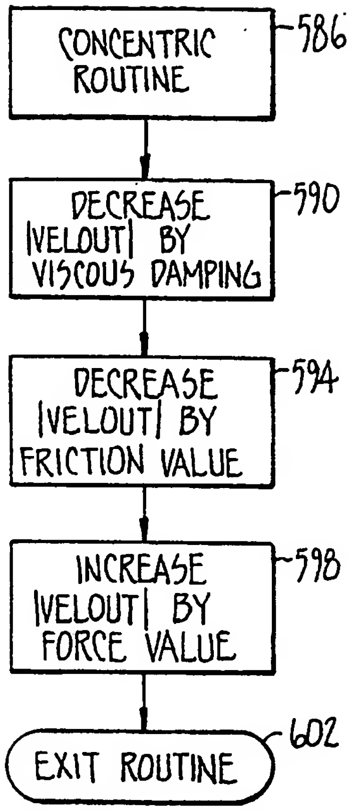

CONCENTRIC ROUTINE
586
DECREASE |VELOUT| BY VISCOUS DAMPING
590
DECREASE |VELOUT| BY FRICTION VALUE
594
INCREASE |VELOUT| BY FORCE VALUE
598
EXIT ROUTINE
602

FIG._11.

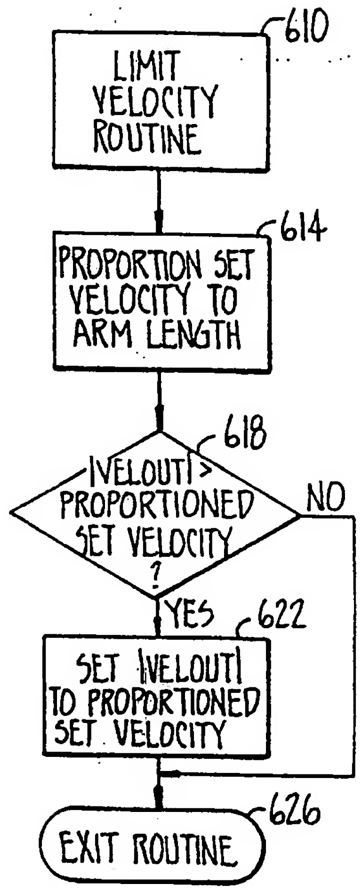
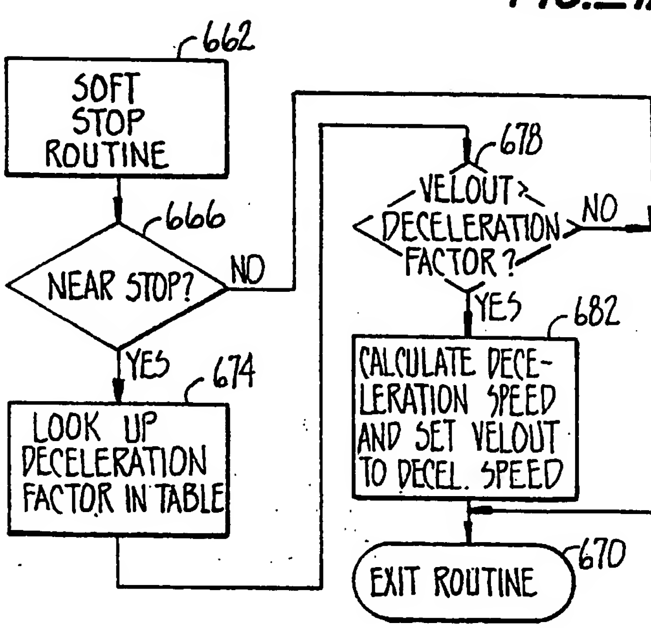

LIMIT VELOCITY ROUTINE
610
PROPORTION SET VELOCITY TO ARM LENGTH
614
|VELOUT| > PROPORTIONED SET VELOCITY ?
618
NO
YES
SET |VELOUT| TO PROPORTIONED SET VELOCITY
622
EXIT ROUTINE
626

FIG._12.


SOFT STOP ROUTINE
662
NEAR STOP?
666
NO
YES
LOOK UP DECELERATION FACTOR IN TABLE
674
VELOUT > DECELERATION FACTOR ?
678
NO
YES
CALCULATE DECELERATION SPEED AND SET VELOUT TO DECEL. SPEED
682
EXIT ROUTINE
670

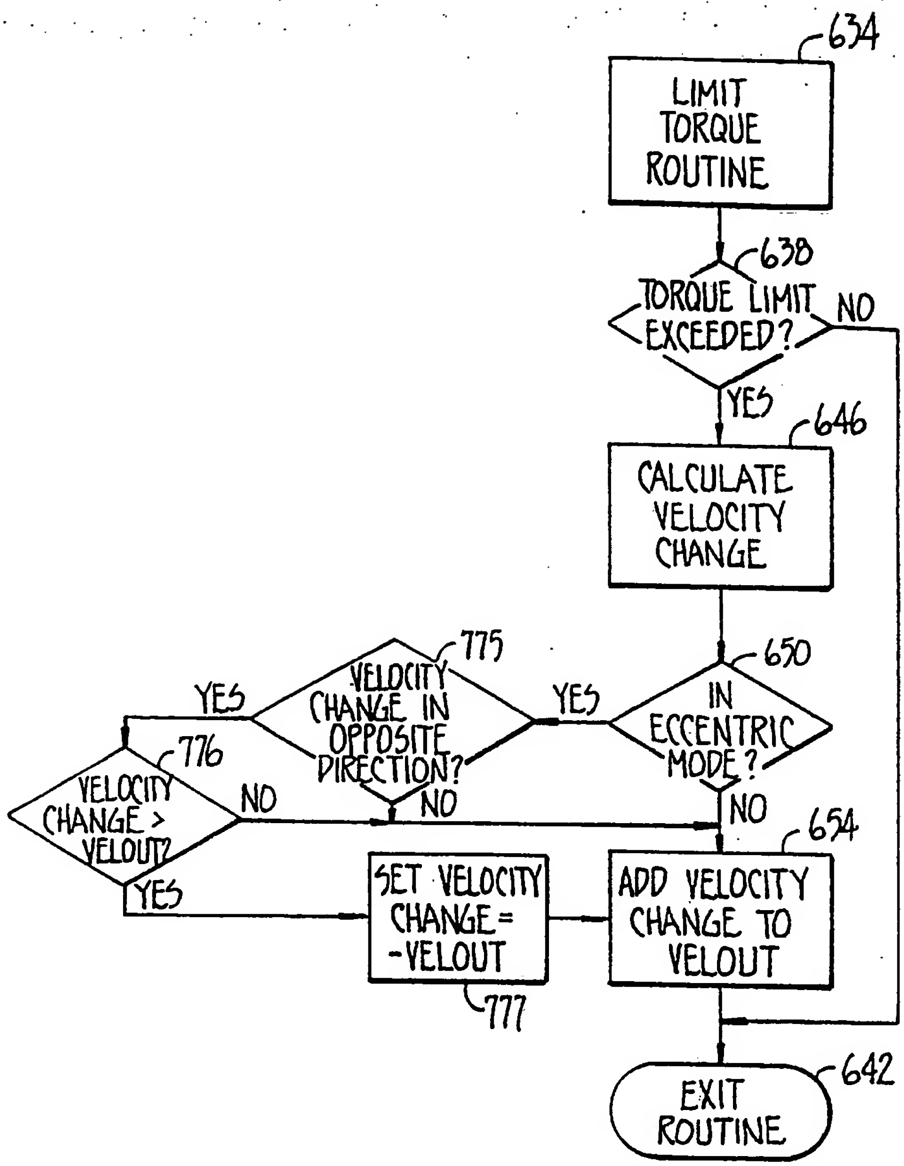

634
LIMIT TORQUE ROUTINE
638
TORQUE LIMIT EXCEEDED?
NO
YES
646
CALCULATE VELOCITY CHANGE
650
IN ECCENTRIC MODE?
YES
775
VELOCITY CHANGE IN OPPOSITE DIRECTION?
YES
NO
776
VELOCITY CHANGE > VELOUT?
NO
YES
NO
654
ADD VELOCITY CHANGE TO VELOUT
SET VELOCITY CHANGE= -VELOUT
777
642
EXIT ROUTINE

FIG._14.

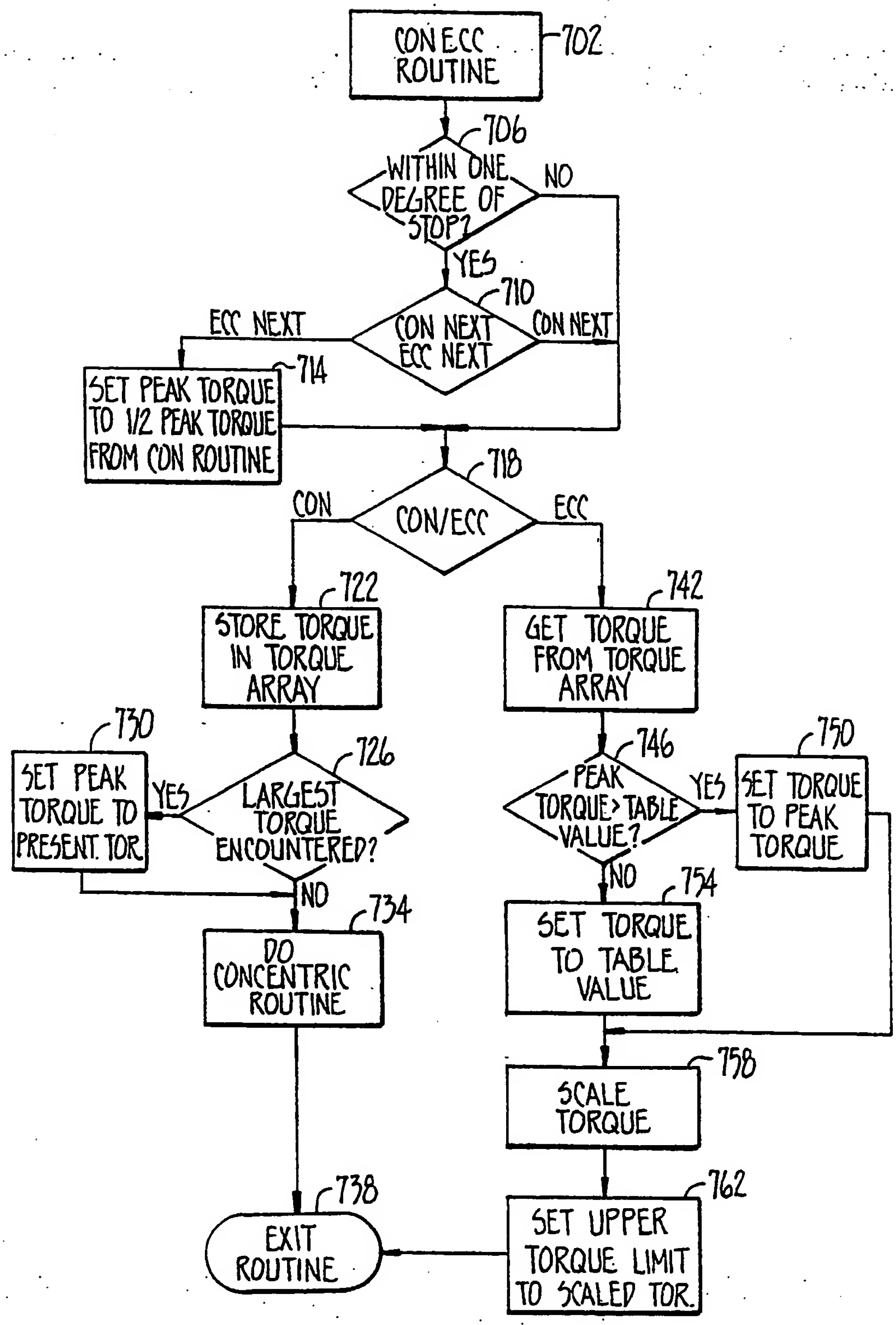

CON ECC ROUTINE
702
706
WITHIN ONE DEGREE OF STOP?
NO
YES
710
CON NEXT ECC NEXT
ECC NEXT
CON NEXT
714
SET PEAK TORQUE TO 1/2 PEAK TORQUE FROM CON ROUTINE
718
CON/ECC
CON
ECC
722
STORE TORQUE IN TORQUE ARRAY
742
GET TORQUE FROM TORQUE ARRAY
730
SET PEAK TORQUE TO PRESENT TOR.
YES
726
LARGEST TORQUE ENCOUNTERED?
NO
734
DO CONCENTRIC ROUTINE
746
PEAK TORQUE>TABLE VALUE?
YES
750
SET TORQUE TO PEAK TORQUE
NO
754
SET TORQUE TO TABLE VALUE
758
SCALE TORQUE
762
SET UPPER TORQUE LIMIT TO SCALED TOR.
738
EXIT ROUTINE

FIG._15.

RIGHT KNEE EXT/FLEX

BOUT (#)	MODE	VELOCITY (DEG/SEC)	REPS (#)	DURATION (SEC)	REST (SEC)	SETS (#)	TORQ. LIM. (FT-LBS)
1	CPM	30/30	10		10	1	60/60
2	CPM	60/60	10		10	1	250/250
3	CPM	90/90	10		10	1	250/250
4	CPM	120/120	10		10	1	250/250
5	CON/CON	60/60	10		10	2	400/300
6	CON/CON	60/60		30	60	1	400/300
7	CPM	5/5		30	10	1	5/5
8	CON/ECC-1	120/60	10		10	1	250/250
9	CON/ECC-2	60/120	10		10	1	250/250

FIG._16.

RIGHT KNEE EXT/FLEX

BOUT (#)	MODE	VELOCITY (DEG/SEC)	GOAL TYPE	BIOFEEDBACK
1	CPM	30/30	PEAK TORQUE	BAR GRAPH
2	CPM	60/60	PEAK TORQUE	BAR GRAPH
3	CPM	90/90	PEAK TORQUE	BAR GRAPH
4	CPM	120/120	PEAK TORQUE	BAR GRAPH
5	CON/CON	60/60	WORK PER REP.	BAR GRAPH
6	CON/CON	60/60	TOTAL WORK	RUNNER
7	CPM	5/5	PEAK TORQUE	TORQUE CURVE
8	CON/ECC-1	120/60	POWER	TORQUE CURVE
9	CON/ECC-2	30/30	POWER	RUNNER

FIG._18.

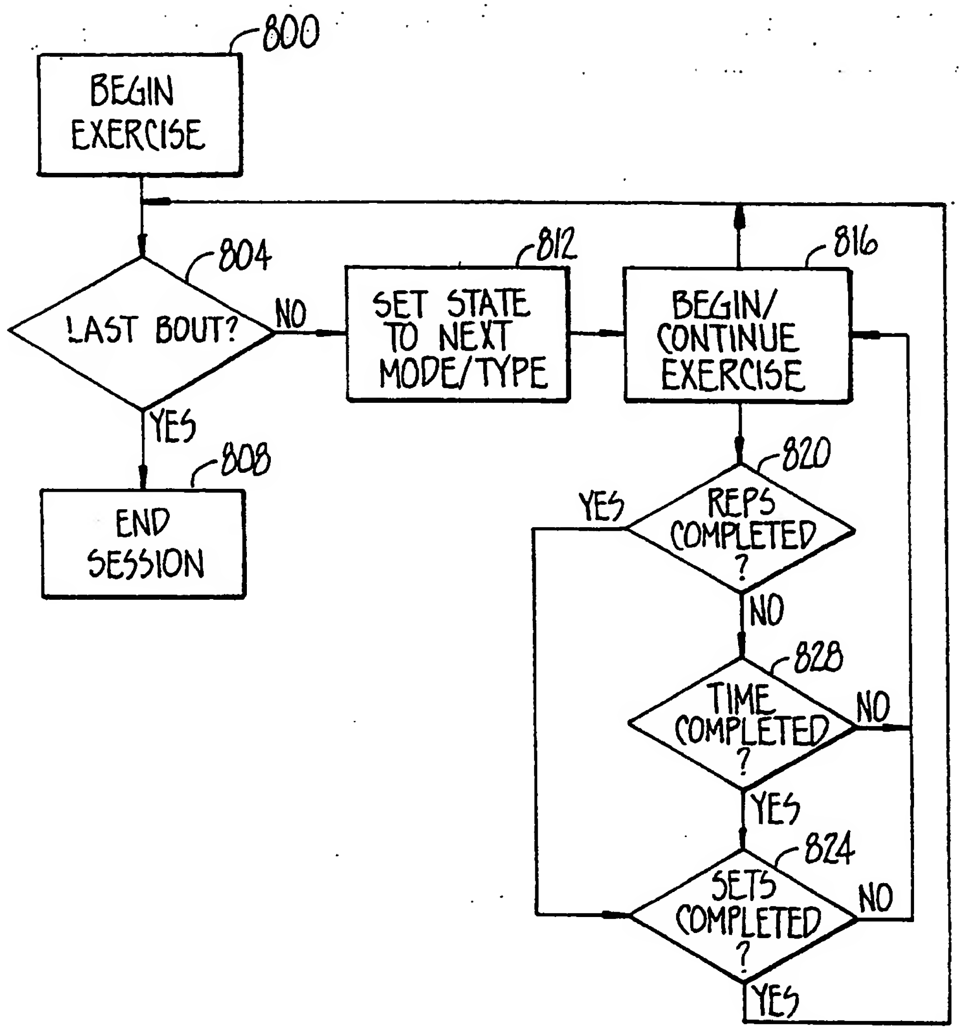

800
BEGIN EXERCISE
804
LAST BOUT?
NO
YES
808
END SESSION
812
SET STATE TO NEXT MODE/TYPE
816
BEGIN/ CONTINUE EXERCISE
820
REPS COMPLETED ?
YES
NO
828
TIME COMPLETED ?
NO
YES
824
SETS COMPLETED ?
NO
YES

FIG._17.

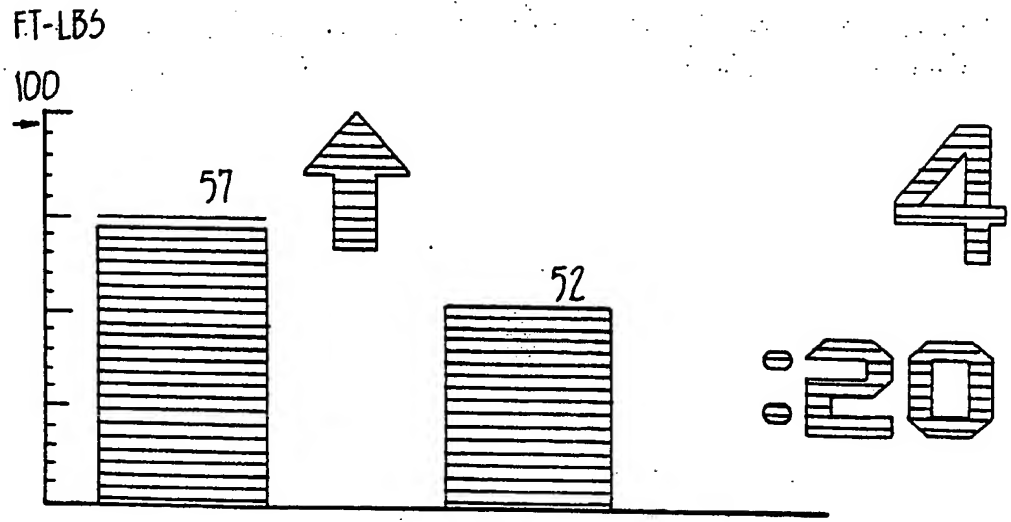

FT-LBS
100
57
52
4
:20
60/60

FIG._19.

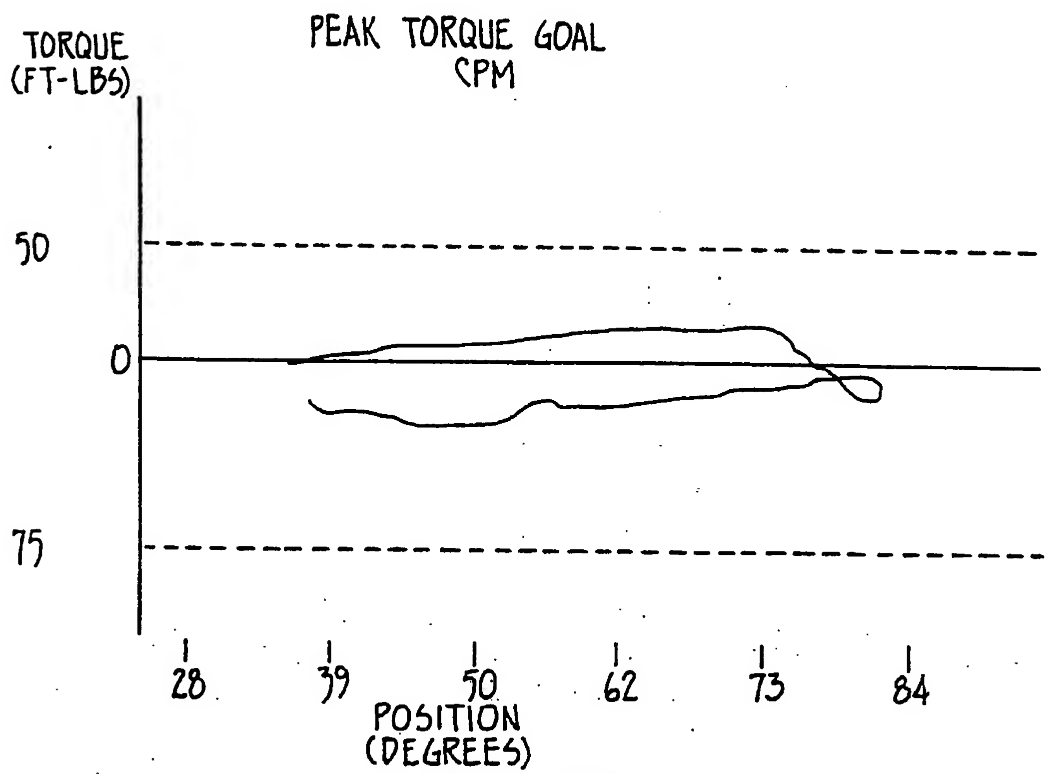

TORQUE
(FT-LBS)
PEAK TORQUE GOAL
CPM
50
0
75
28
39
50
62
73
84
POSITION
(DEGREES)

FIG._20.

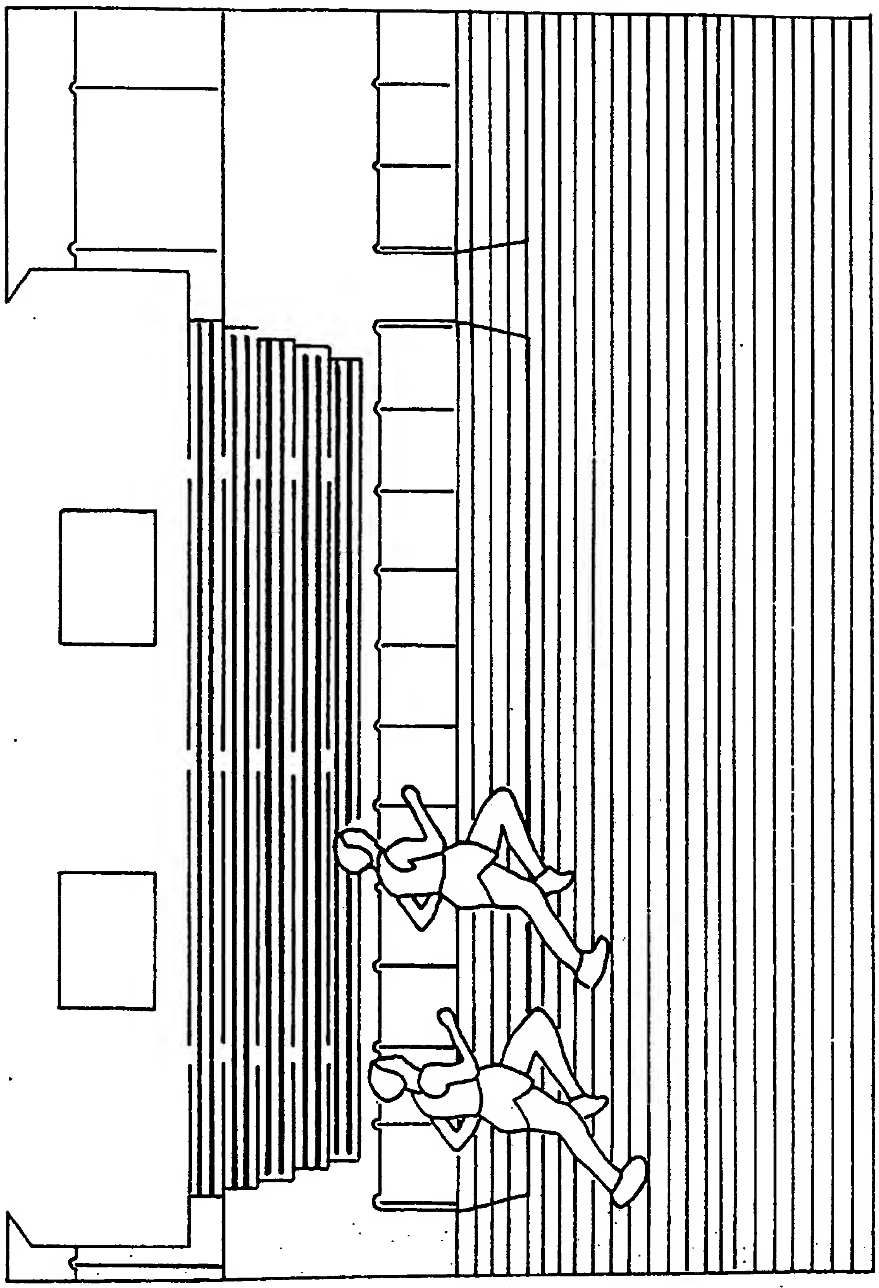


FIG._21.

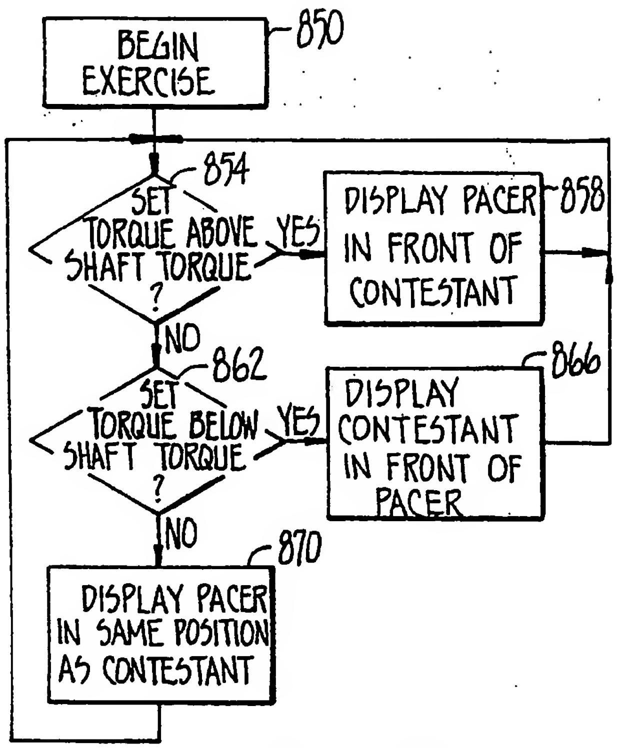

BEGIN EXERCISE
850
SET TORQUE ABOVE SHAFT TORQUE ?
854
YES
DISPLAY PACER IN FRONT OF CONTESTANT
858
NO
SET TORQUE BELOW SHAFT TORQUE ?
862
YES
DISPLAY CONTESTANT IN FRONT OF PACER
866
NO
DISPLAY PACER IN SAME POSITION AS CONTESTANT
870

FIG._22.

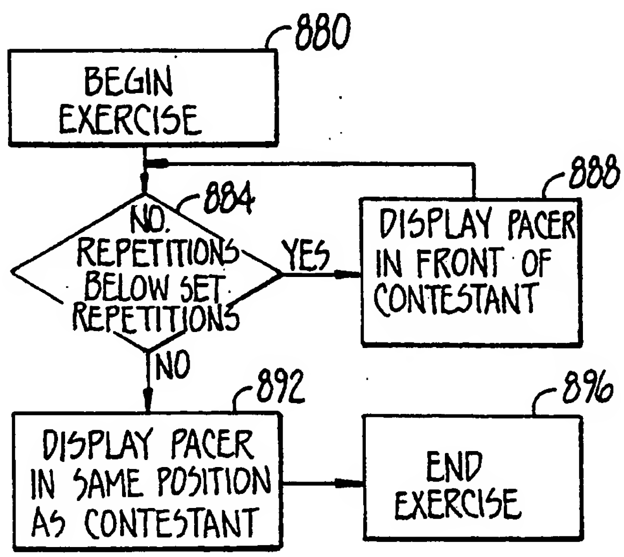

BEGIN EXERCISE
880
NO. REPETITIONS BELOW SET REPETITIONS
884
YES
DISPLAY PACER IN FRONT OF CONTESTANT
888
NO
DISPLAY PACER IN SAME POSITION AS CONTESTANT
892
END EXERCISE
896

FIG._23.

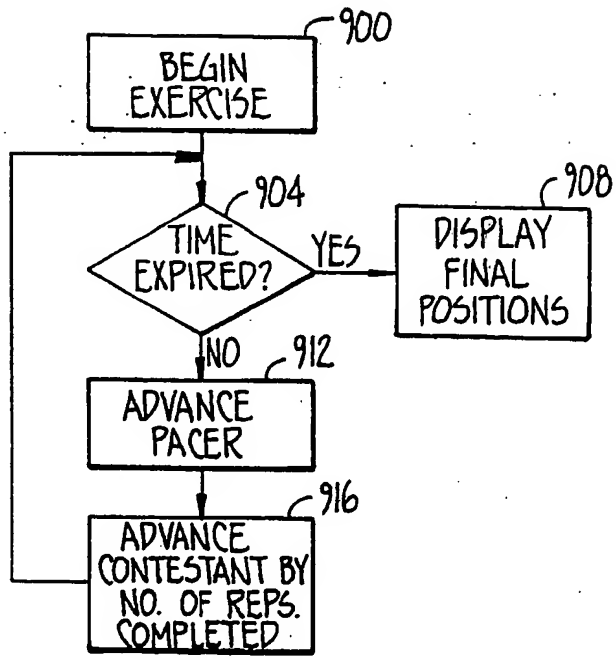

900
BEGIN EXERCISE
904
TIME EXPIRED?
YES
908
DISPLAY FINAL POSITIONS
NO
912
ADVANCE PACER
916
ADVANCE CONTESTANT BY NO. OF REPS. COMPLETED

FIG._24.

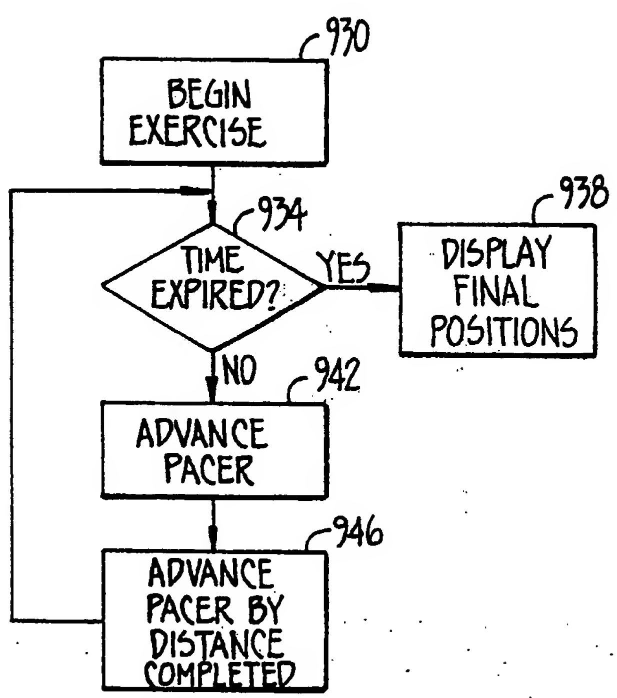

930
BEGIN EXERCISE
934
TIME EXPIRED?
YES
938
DISPLAY FINAL POSITIONS
NO
942
ADVANCE PACER
946
ADVANCE PACER BY DISTANCE COMPLETED

FIG._25.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US91/00409

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) A63B 21/100
US CL 272/73

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	272/73, 125, 129, DIG.6, 132

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
P, Y	U.S.A., 4,934,694 (MCINTOSH) 19 June 1990 See the entire document	1-11
X	U.S.A., 4,542,897(MELTON) 24 September 1985 See the entire document	12-20
X	U.S.A., 4,674,741 (PASIERB, JR. ET AL.) 23 June 1987 See the entire document	12-20

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
06 March 1991	15 MAY 1991
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Glenn Richman

Form PCT/ISA/210 (second sheet) (May 1986)